Growth **21**, 53 (1957); M. Harris, *Cell Culture and Somatic Variation* (Holt, Reinhart, and Winston, New York, 1964); L. Levintow and H. Eagle, *Ann. Rev. Biochem.* **30**, 605 (1961); M. M. Swann, *Cancer Res.* **18**, 1118 (1958); K. G. Lark, in *Molecular Genetics*, J. H. Taylor, Ed. (Academic Press, New York, 1963), p. 153; B. N. Jaraslow, *J. Infect. Dis.* **107**, 56 (1960); V. Menkin, *Cancer Res.* **1**, 548 (1941); J. N. Davidson, *Edinburgh Med. J.* **50**, 70 (1943); B. Miletić, D. Petrović, L. Zajec, *Nature* **197**, 90 (1963).

49. N. J. Berrill, *Biol. Rev.* **26**, 456 (1951).
50. W. Bieling, *Arch. Entwickslungsmech. Organ.* **137**, 1 (1937); W. Ernst, *Anat. Entwicklungsgeschicte* **79**, 228 (1926); L. Gräper, *Verhandl. Anat. Gesellschaft* **43**, 125 (1935 E. Kallius, *ibid.* **40**, 19 (1931); W. Stockenberg, *Arch. f. Entwickslungsmech. Organ.* **135**, 408 (1936).
51. E. Deuchar, *Soc. Exp. Biol. Symposia* **17**, 58 (1963).
52. E. J. Boell, *Anat. Rec.* **105**, 600 (1949); M. Spiegel, *Biol. Bull.* **126**, 307 (1964).
53. C. E. Wilde, *Ann. N. Y. Acad. Sci.* **60**, 1015 (1955).
54. J. W. Saunders, Jr., W. C. Quevedo, L. Pierro, F. E. Morbeck, *J. Nat. Cancer Inst.* **16**, 475 (1955).
55. S. M. Gartler, *Biochem. Biophys. Res. Commun.* **3**, 127 (1960); W. O. Rieke, *J. Cell Biol.* **13**, 205 (1962); G. F. Rabotti, *Exp. Cell Res.* **31**, 562 (1963); E. Szybalska and W. Szybalski, *Proc. Nat. Acad. Sci. U.S.* **48**, 2026 (1962).
56. M. C. Niu, in *Acidi nucleici e loro funzione biologica* (Tipografia Successori Fusi, Pavia, 1964), p. 352; N. W. Hillman and M. C. Niu, *Proc. Nat. Acad. Sci. U.S.* **50**, 486 (1963); J. Butros, *J. Exp. Zool.* **154**, 125 (1963); *J. Embryol, Exp. Morphol.* **13**, 119 (1965).
57. M. C. Niu, C. C. Cordova, L. C. Niu, C. L. Radbill, *Proc. Nat. Acad. Sci. U.S.* **48**, 1964 (1962); H. Amos and K. E. Kearns, *Nature* **195**, 806 (1962); E. Zimmerman, M. Zoller, F. Turba, *Biochem. Z.* **339**, 53 (1963); A. S. Weisberger, *Proc. Nat. Acad. Sci. U.S.* **48**, 68 (1962); L. Kraus, *Nature* **192**, 1055 (1961); S. De Carvalho, H. J. Rand, J. R. Uhrick, *Exp. Mol. Pathol.* **1**, 96 (1962).
58. J. A. Mannick and R. H. Egdahl, *Science* **137**, 976 (1962); E. P. Cohen and J. J. Parks, *ibid.* **144**, 1012 (1964).
59. B. M. Askonis and J. M. Rhodes, *Nature* **205**, 470 (1965); H. B. Friedman, A. B. Stavitsky, J. M. Solomon, *Science* **149**, 1106 (1965).
60. P. Banon, D. Brandes, J. K. Frost, *Acta Cytol.* **8**, 416 (1964), suggested that macrophages of the endometrium may digest and deposit into the blood stream material from the mucosa.
61. The research of the author, his students, and collaborators herein reported received support from NIH grants C-1481, GM-07603, and GM-09996 and NSF grants G-2253, G-5006, and G-14439, and from awards by the American Cancer Society, Milwaukee Division. Parts of the work were carried out at the Marine Biological Laboratory, Woods Hole, Massachusetts. I thank Mr. Stanislaus Ratajczak for assisting in the preparation of the illustrations, Drs. C. M. Williams and R. A. Lockshin for permitting review of their recent manuscripts in advance of publication, and Dr. E. Zwilling for a number of stimulating discussions. Dr. Zwilling's recent paper in *Cellular Injury*, A. V. S. de Reuck and M. P. Cameron, Eds. (Churchill, London, 1964), p. 352, provides other insights into the significance of developmental death.

Oases for the Future

New trends in gaining, using, and conserving fresh water are here or on the horizon.

Kenneth Hickman

We are repeatedly told there is a water problem. What is it, and where? In the broadest, average sense, there is none at present. World population stands at about 3×10^9 persons. Under the most extravagant conditions of use—agricultural, industrial, and domestic—the amounts used add up to about 2.2×10^5 gallons (8.3×10^6 liters) per year per capita (*1*), or a world total of 6.6×10^{14} gallons. The known world supply (*2*) of "fresh" fresh water is about 1.4×10^{16} gallons per year, or 50 times as much as anybody can need. Even by the year 2000, when the population may have doubled, the ratio of available water to needed water will be approximately 25 to 1.

These are gross average figures; the regional situation is very different. Most rain falls on wasteland, and much of this rain evaporates; perhaps 30 percent finds its way to rivers, and of this some 15 percent flows unused into the ocean (*3*). Thus the amount of available fresh water is some 2.0×10^{15} gallons per day, or about twice the total needed and enough, on the average, to meet the needs of the year 2000 but not those of the year 2010! The average is, of course, a fiction. Water, like air or money, is fantastically plentiful, but some people never have enough and some have none at all. These people and situations are our concern *now*.

Narrowing the inquiry to the terrestrial United States, we find that the gross daily precipitation is about 4.3×10^{12} gallons (*4*), the net yield from rivers and lakes is about 6.5×10^{11}, and the gross average demand is about $(185 \times 10^6 \times 2.2 \times 10^5)/365$—say 1.12×10^{11} gallons. Thus the ratio of available to needed water is roughly 5 to 1. But this is an average. Actually, an area of a million square miles (2½ million square kilometers) west and south of the Rockies is essentially without water, and the Great Lakes region has a surfeit. The situation in New York State may be evaluated (*5*) in terms of reservoirs and time rather than gallons and people. During the period of 1959 to 1965 the rainfall was less than the average 42 inches (107 centimeters) per annum in every year except 1960, the deficit totaling about 80 percent of one year's fall. The reservoirs, as of December 1965, were 33 percent full, but they are now (September 1966) 67 percent filled (*6*). Will swings of the rain cycle completely make up the deficiency? For short periods, undoubtedly yes, but not, I think, over the long pull. Our use of fuel appears to be increasing more rapidly than world climate is changing. The energy received from sunlight is of the order of 3.2×10^{16} British thermal units per 10^6 square miles per day (*7*). In North America, the energy released by human activity has reached a total of about 6×10^{13} British thermal units per day, adding 0.2 percent to the energy received from the sun, enough to raise the temperature by 0.6 degree Celsius. But this energy release is concentrated in three regions—the Eastern Seaboard, the Chicago–St. Louis central area, and the Los Angeles basin. In the first and third of these areas, in particular, the ratio of heat from fuel to heat from the sun is much higher than the average value. In these regions, too, carbon dioxide and other atmospheric pollution foster development of a radiation-heat trap which may increase the dry-bulb temperature by 3.6 or more degrees Celsius over areas of 1000 square miles. Civilization creates its own drought in proportion to its concentration of people and thus of water needs —and the situation will get worse. The

---

The author is professor of experimental research, Rochester Institute of Technology, Rochester, New York. This article is based on a talk given at the joint meeting of the French Engineers in the United States and the American Section of the Societé de Chimie Industrielle, held in New York in February 1966. The text of the address appeared in the August 1966 issue of *Chimie et Industrie*.

use of energy is said to be increasing exponentially. Add to this the quantum jump of the discovery of atomic fuel, with its promise of a millionfold increase in energy, and one glimpses an appalling problem for the future: how to alter the albedo of the earth in order to make the earth reject the sun's heat, or how to export heat by means of a thermodynamic cycle (as yet undiscovered) that will leave the world cooler. But I am ahead of my story.

Outside of North America and northern Europe there are few water-rich regions. Large parts (about half) of India, China, and North Africa are arid; so are two-thirds of Australia and Asia Minor, and all of Arabia. Islands having no rivers are intermittently short of water. The Westman Islands, off the coast of Iceland, which, on the average, have as much fresh water per unit area as any other part of the world, run short of drinking water for the fishing fleet each summer (*8*). The Dominican Republic, adjoining the mountains of Haiti, has a desert rivaling Death Valley, though it is in the humid Caribbean. In the Bahamas, water to drink may cost $1 a gallon. A resort hotel in Jamaica which charges $60 a day per room is said to spend $6 of this for fresh water (*9*). Small units, ranging from farmhouses to small towns, which have been dependent for fresh water on deep wells are finding these wells turning saltier each year. This experience applies equally to such diverse areas as the Michigan peninsula, the San Fernando Valley in California, parts of Florida, and the Bahama Islands.

Can we say, then, that there are water-poor areas with a problem now, other areas where there will be a problem, and water-rich areas with no foreseeable problem? Not so. There is a widespread water problem *now*, and it is increasing. The compelling reason for this is inadequate waste disposal—pollution. The rule of thumb is: Where there is a shortage, the problem is where to get water; where there is plenty of water, people and cities congregate, and the problem is where to put the waste. The Great Lakes constitute the world's largest accessible supply of fresh water, yet Lake Erie, serving Toledo, Cleveland, and Buffalo, is already polluted to the point of health hazard (*10*).

The real dichotomy, then, is not water-rich or water-poor but large-scale or small-scale, regional or isolated.

Conversion or Processing versus Conveyance

How much does it cost to turn sea water or sewage into fresh water? Ten years ago, perhaps $5 per 1000 gallons; 2 years ago, $2; and this year, less than $1. And there are plans on the drawing boards for plants that will lower the cost to 50 and even 25 cents per thousand gallons. But the progression denotes not so much the passage of time as a trend toward very large plants; a figure of 25 cents per 1000 gallons is for a 150-million-gallon-per-day plant. (How much does sand cost? It depends on whether you pick up a bagful, order a carload, or move a mountain.) It has been suggested (*11*) that, with increasing size of operation, the cost of delivered water should decrease at a faster rate than the cost of converting water—that if you want *enough* it may be cheaper to bring water from Baffin Bay to Tierra del Fuego than to convert sea water at the tip of South America. The same rule applies to waste disposal; if there is enough waste it is worth while taking it to the ocean, where it can become marine fertilizer for plankton and indispensible for increasing the fish life to feed the future world population. To my mind the three-part challenge—to bring water, convert sea water, and take away waste—ushers in one of the great, yet hardly recognized, technological revolutions of our time.

Evolution or Revolution?

The word is *revolution*—peaceful, but decreed by the most relentless of dictators, necessity. And here let me elaborate on the "oases" of the title. I am thinking in terms, not of palm-fringed patches of green in the desert or of golf courses in arid lands, but of gardens made to bloom in dusty towns; of new water brought to grubby people; of opportunities for entrepreneurs and builders in present wastelands and on dry islands and sandbars. Even more, I am thinking of an oasis of the mind—a quickened awareness of new opportunities encompassing the fields of engineering, conservation, chemistry, biology, and the weather sciences.

The overall revolution, then, is in the environmental sciences. Within it are three related revolutions.

1) A revolution in the management of the primary water supply, including conservation and management of climate and precipitation.

2) A revolution in methods of water conversion and processing.

3) A revolution in patterns of water use and reuse, industrial and personal.

Water Supply

Our national furor over water conversion has kept us unaware, perhaps, of the importance of a recent gigantic water-diversion project in Australia. There the great inland desert is bordered on the east by the Snowy Mountains, parallel to, and near, the coast. The mountain range strips the ocean breezes of their humidity and discharges the precipitation into east-flowing rivers which serve Brisbane, Newcastle, and Sydney and then pass, mostly unused, into the Tasman Sea. The Snowy Mountain–Tumut project (*12*) reverses three of the larger rivers, tunnels them westward through the mountains into dammed-up canyons (now magnificent man-made lakes), and drops the water down, in stages, through powerhouses—already producing a total of 1.3×10^6 kilowatts (the figure will be 2.5×10^6 by 1975)—to stabilize the flow of the Murray and Murrumbidgee rivers and the water supply of their arid valleys (*13*).

Well-known in our own country are the damming of the Colorado River and the diversion of its water to Los Angeles, the Imperial Valley, and Mexico (*14*); the still earlier diversion of the Owens Valley water (*15*); and now the huge Feather River project in Northern California. Not yet of prime public concern are the proposals of the North American Water and Power Alliance (*16*), which far outrank, in magnitude of engineering concept and anticipated human benefit, any other water-diversion project yet envisaged. A continental divide passes roughly east-west from Labrador through lower Canada to Alaska, and rivers to the north flow into the Arctic Ocean. Much of the country they serve is uninhabited, so that the runoff surviving, after relatively little evaporation, constitutes the largest body of *unused* fresh water in the northern part of the continent. It is proposed to bring, over a period of 30 years and through expenditure of perhaps $200 billion, 160 billion gallons per day to the Middle West, the desert regions, and areas as far south as Mexico. This amount is greater than the total present

U.S. consumption. A charge would be made for this water, bringing, even at such a nominal price as 5 cents per thousand gallons, a half billion dollars annually into the Canadian treasury. One foresees a time when Russia might reverse the Ob, the Lena, and the Yenisei to provide water for domestic use and export.

Here we sense another unheralded revolution, with power becoming so cheap and big that it is now profitable to pump uphill what had been our cheapest source of power when it flowed downhill!

The river waters that flow into the Arctic Ocean warm it and, themselves, become colder and part of the southbound currents that carry cold water across the continental shelves and ocean bottom to the Equator. If these waters should be artificially brought back overland, one would expect the Arctic to grow a trifle colder, the tropics to grow warmer, North America to be warmer and snowier in winter and cooler in summer, and the world climate to change. Mass balance studies (*17*) suggest that, of all the moisture supplied from the oceans to the air entering the region of the United States, 90 percent can be accounted for in the air that leaves the region. This means that the moisture contribution from outside areas is only 10 percent. Precipitation, however, may reach 20 percent of the moisture content of the incident air; hence we must conclude that each moiety precipitated is reevaporated and reprecipitated before it finds its way back to the ocean. This is good news, because it suggests that, for each gallon pumped in or converted from sea water, another gallon will fall somewhere in the country. This is small comfort to a man spilling a gallon of water on his porch, because the dividend could be spread over 4 million square miles; but when everybody is spilling extra water, everybody stands to receive still more water. All of which warns us that climatic factors are subject to regenerative amplification and may produce fearsome consequences.

This brings me to the subject of new water from the skies. Having rearranged our rivers to the limit of our ability, we seek further precipitation. That ice floats and that snow is white are but two of the features of the hydrosphere that make life-as-we-know-it feasible on this planet. A third is the stability of the clouds. Cloud seeding notwithstanding, we simply do not know (fortunately!) how to coagulate dilute clouds and fogs in the way we can coagulate custard or clay or sewage effluent. The political and military consequences of an acquired ability to dump skyfuls of water at will do not bear contemplation. But we need not, on this account, reject the search for new means of increasing precipitation in reasonable, controllable amounts. For a lead we might look to nature. On favorably oriented mountainsides and in rain forests we see vegetation encouraged to prolific growth by the pattern of rain. Thinking teleologically, may we not inquire whether vegetation, through the self-serving knack that is acquired by most living things, may have learned to encourage rain—to make it more likely that the clouds will precipitate where the trees are? I have always been intrigued by the massive display of fall colors. Why do thousands of square miles change from green to brown and red? Is it to remind the bears and hedgehogs and squirrels to lay away provisions or get to their burrows, or is it a concerted cry to the clouds (copied at any season by the sere and yellow leaf and the grass parched in drought)—a concerted shout, *we want water!* I don't know, but I inquire. If there is a message, is it in the photoelectric potential of color or the chemistry of the color change? A fragment of chlorophyll or carotene or terpenoid vaporized into the wind? It might be worth finding out.

Conversion Process

There are many ways of separating impurity from water or water from impurity, but all have two things in common: energy is consumed, and the separation occurs at a surface or interface—at a screen, of molecular dimensions—through which the water can pass and the salt or other impurity cannot, or vice versa. I know of only one process in use that takes the salt out, leaving the water behind; that is electrodialysis, which has been very successfully used in the treatment of brackish water. Two towns in the United States—Webster, South Dakota (*18*), and Buckeye, Arizona (*19*), operate with water purified in this way (at a cost of 60 to 70 cents per 1000 gallons) before distribution. The key to economical conversion lies in minimizing the power consumption and extending the life and penetrability (freedom from clogging) of the separation surfaces.

One might ask why nature readily makes the fresh water that the chemical engineer finds it so expensive to produce. Nature has available 100 million square miles (about half the area of the earth's surface) of sufficiently warm separation surface, and energy from the sun. It is calculated that man could match nature as a distiller of water if 3 out of every 4 square miles of land were covered with solar stills, and civilization was relegated to the remaining square mile! No, at present solar distillation is for survival only, though "survival" can be interpreted broadly. The town of Symi (*20*) on a small island of the same name in the Aegean was losing both residents and summer visitors through want of water. The World Church Organization offered to supply a large solar still. But where to put it? The only level ground was the town square. Today the town square *is* the world's largest solar still, and Symi again flourishes.

The power economics of sea-water conversion requires elaborate computation (*21*) but may be simply stated (*22*). The theoretical minimum quantity of heat (that is, disordered energy) needed to separate salt from sea water is 1 British thermal unit for each pound of product water. This is a totally unrealizable ideal. With any conversion scheme yet devised, allowance of a factor of 3 should be made for reversibility either of the conversion process or of the engine that drives it. Perhaps a further 3 British thermal units are needed to overcome losses due to concentration increases, friction, and other factors entailed when the process is carried out at a useful rate. These considerations lead to a practical theoretical minimum heat cost of 6 British thermal units per pound of product. If, however, water is distilled in an efficient boiler fired with oil or coal (or nuclear fuel), some 1200 British thermal units are consumed per pound of product water—a realized yield 200 times less than the theoretical minimum, or an efficiency of 0.5 percent! The rest of this huge quantity of heat is wasted in the water needed to cool the steam condenser. The remedy is to reuse the discarded heat, and reuse it as many times as possible.

Consider a pan of water on the stove. Above this we place another pan, and on this another and another and another until the stack reaches the ceiling. In each pan, if it is done right, water can be evaporated in about the same quantity as in the pan underneath but at a lower temperature, and, from each pan-pair, distillate can be drawn. Starting with the bottom pan at boiling point and keeping the top pan at tap-water temperature through constant refilling, we shall be lucky if we can stack 18 pans in between and have the cascade operate; this, in a double sense, is the ceiling of our efficiency. Of course, steam will be leaking from around the edges and the stack will be getting cold, so the yield of water may equal only 16 reuses instead of a possible 19. Sixteen multiplied by 0.5 = 8-percent theoretical-practical efficiency; this is the very best we can do under so low a ceiling.

The principle of heat reuse has long been known. There have been multiple-effect stills on ships for many years. When oil was discovered in Arabia the need for artificial fresh water and the availability of money and fuel to provide such water occurred simultaneously. Multi-effect stills were installed in Kuwait in 1953, and at present (*23*) there are installed multi-effect and flash stills, with reuse factors ranging from 5 to 10, having total daily capacity of 13 million imperial gallons. On the other side of the world, off Venezuela, the island of Aruba, also a water-poor, oil-rich focus of capital investment, has had multiple redistillation equipment for many years and now can distill over 4 million gallons daily (*24*).

Must we be content with a ceiling of 20 reuses? To reach the theoretical limit of 200 reuses it would be necessary to begin distilling water at temperatures above the critical point, a physical impossibility. Reasoned another way, to extract energy efficiently from fuel, the heat must be used at the highest practical temperature and discarded at the lowest. Fuels burn at about 1650°C, yet the heat has been used hitherto only below 120°C in the sea-water still. The rest of the available *power* is wasted. Fortunately, there is a way out: to use the fuel heat first in a high-temperature steam boiler at, say, 590°C for salable power and then to exhaust the steam at 150°C for use in the desalting process. This procedure is not to be confused with the ancient search for "free" heat but is a well-nigh inescapable part of any high-efficiency water-conversion scheme driven by a heat engine. It seems likely that most of the gigantic conversion projects now under construction or in the planning stage will combine desalting with power production. This suggests that we will be saying to the consumer, "You may have your water but you must buy some power too and take both in a fixed ratio whether or not you want both!" Again, fortunately, this is not the case. Some of the well-tried desalting processes, like compression distillation and electrodialysis, require power instead of direct heat, and reverse osmosis, considered by many tomorrow's most promising scheme, will use power almost exclusively. By-product power can be deflected to convert water. The community of the future can have water and power in whatever ratio it wants.

Improvements in the distillation cycle are being made rapidly. The multiple-stage still (*25*) has been all but superseded by the multi-effect flash still and combinations of the two (*26*). So much is likely to be heard about flash distillation that a brief description is in order.

Imagine a long metal tunnel laid on flat ground. Inside, near the roof, there are long rows of pipes with trays or drip pans beneath them. Cold sea water is pumped through the pipes from, say, the left end and allowed to issue from the right end. Now, suppose boiling sea water is poured into the tunnel at the right end and allowed to flow to the left end and to waste. This water is evaporating throughout its course along the floor of the tunnel, and steam is rising and condensing on the cold pipes overhead and dripping into the catch pans. This is our product water. The water in the pipes near the ceiling gets hotter as it progresses through them, and it emerges from the tunnel almost boiling. This is the "free" supply (from reuse heat) of hot, new sea water, and it is necessary only to put it through a relatively small heater to bring it a little above boiling point. It is then allowed to flow back, down the floor of the tunnel, to the ocean. When it reaches the ocean it is only a little warmer than when it first entered.

There is more to a complete flash still than this. The tunnel is divided into many compartments, each at a different steam pressure, and there are innumerable pumps, weirs, and controls. But, despite a frighteningly complex layout, this is essentially a simple process and is one of those mentioned for the 150-million-gallons-per-day plant (*27*) to be erected on an artificial island off the coast of southern California and perhaps for the 100-million-gallons-per-day installation for the State of Israel to be constructed under a joint scheme with the United States.

I myself am a compression distillation enthusiast (*28*). In principle, this is the simplest of all known cycles. Imagine a boiler full of hot water but with no fire underneath. Instead, steam from the boiler is put through a compressor and fed into the firebox. The compressor has made the steam hotter and denser, so it condenses on the boiler tubes to form pure water, repays the heat it borrowed when it evaporated, and keeps more steam coming to the compressor. The process continues as long as new water is fed to the boiler, the used-up strongly salt water is removed, and the compressor is kept going. A boiler, a compressor, and two pumps can comprise the entire machine. Compare this with the "hydraulic telephone-exchange" appearance of the multi-unit water stills!

Paradoxically, purification by freezing (*29*) compares favorably with the compression still method, because this too is a form of compression distillation. Steam may be withdrawn from the water surface to freeze the water and then be recompressed, or a refrigerant like propane (*30*) or freon can be added directly to the crude water or confined in a conventional refrigerator engine to freeze the water. I shall discuss the first case because of its simplicity. But before I do, I might answer the anticipated question, Why use freezing at all? The reason is that the purification interface is now the junction between the ice and the crude water, instead of being a still wall or man-made membrane. The latter are permanent fixtures to be maintained and cleaned, while the ice is ephemeral and remade anew with each drop of water purified.

Arctic ice is sometimes formed so slowly that the crystals consolidate into clear salt-free masses from which the brine has been squeezed. Man-made ice from sea water is a mush of microscopic crystals of large surface-to-volume ratio, which entrain most of the brine they have rejected. The freezing process, then, poses two problems —how to filter the ice and how to recompress the steam. The first has been solved, but the second is far more difficult because the vapor from water at −6.7° to −3.9°C occupies some 400 times the volume of ordinary steam. A compressor must be of tremendous size but must remain simple or it will cost too much. Now, one can well imagine an Arctic island being selected as the site for a freezing device, but history relates that the first such device was constructed in one of the world's hottest regions, at Eilat, on the Gulf of Aqaba. It was designed by A. Zarchin (*31*) for the State of Israel, and Zarchin was apparently the first to realize the need for simplifying the compressor down to Tinker-Toy specifications. In this he has been successful (*32*), though whether the process can be competitive with others is not yet certain; the installation at Eilat has worked promisingly for limited periods. However, the evolution of a cheap, high-volume compressor bodes well for ordinary compression distillation at ambient temperature in hot climates.

The last conversion process to be considered here is high-pressure diffusion, somewhat reminiscent of pressure filtration and commonly referred to as reverse osmosis. The need here is for a membrane that will let water through but bar impurities, particularly salt. Sydney Loeb of the University of California has taken the first large step in this direction by showing that ordinary cellulose acetate of "artificial silk" fame, but prepared in a nonordinary way, has the required properties. Imagine a film a thousand times thinner than a plastic wrapping sheet, yet required to withstand pressure of 2000 pounds (or more) to the square inch (136 atmospheres). To provide the necessary mechanical strength the micron-thin working layer must be backed up with layers of ever-more-porous structure until the package can rest on a solid metal grid. Recently Loeb and J. W. McCutchan have put a reverse-osmosis plant of 5000-gallons-per-day capacity into successful operation at Coalinga, California, beside the well-tried electrodialysis installation operating there for the last 5 years.

These are typical of the many existing methods, some of them currently successful, others giving promise for the future. It is my conviction that, as the needs develop, the prices will be right.

Reuse and New Patterns of Use

Because of rapid advances in pollution control, the terminology often contains contradictions. Fresh water that has cooled a power plant or quenched a steel ingot is "used" water, and water drawn from a well is "new," yet the former has been contaminated with little but heat, while the latter may have acquired bacteria and detergent from a neighbor's effluent. Planned sequential use by consumers who will not be affected by the previous consumer's contributions could yield a large increase in supply. Industrial waste must soon be considered separately from municipal effluent, and that, in turn, from storm-sewer and other runoff waters, now indiscriminately bulked as sewage. This simple change alone, in our biggest cities, would require multi-billion-dollar investments but would bring major relief to increasingly taxed facilities. Again, the small industry with toxic waste—electroplating is an example—will have the choice of installing a recovery unit or discharging waste to the community's toxic-effluent-collection system, where such a system is available; large industry will be compelled, under statute, to upgrade its own effluent before discharge. Pulp mills and canning factories will perhaps combine this compulsory chore with voluntary reclaim of commercial values. Municipal sewage, carrying domestic contamination, is already yielding to physical-chemical cleanup processes which involve foaming the sewage with air and filtering it through sand and activated charcoal—to the point where little remains in the water except minerals and salt. However, no matter whether the methods used are palliative measures or complete rejuvenation, there will remain, as for sea water, an ultimate residue requiring disposal (*33*). Indeed, future archeologists may identify our civilization by our midden-heap concentrates. All kinds of suggestions have been made for their disposal: subterranean recharge, filling of old mines and quarries, and even sealing of concentrates in plastic bags (with consequences, on a summer's day, that one dare not contemplate.) The problem will be particular and local, each case demanding a unique remedy, but all being amenable to typing and group treatment in sufficiently crowded areas. As hinted earlier, I think the ultimate destination for large masses of organic waste should be the ocean, conveyance there being by pipe or tunnel.

Costs of water recycle are expected to be lower than costs of desalinization, but not spectacularly so. Water fresh from the ocean has to be pumped to its destination. Water for recycle is already at hand. Consequently one envisages desalinization for coastal cities and conservation of river water for inland cities, with greatly diminished quantities passing to the ocean. Where specially adapted means can be employed—for example, use of foaming and activated carbon—sewage processing is much cheaper than desalinization, but it is not much cheaper when reclamation is total. Though the low solid content—perhaps a fiftieth that of sea water—reduces the postulated "ideal" energy consumption, the additional power needed to "drive" the reclamation process at an acceptable rate is not lowered. Total reclamation has one advantage seldom mentioned—the direct use that could be made of "pure distilled" grade water in industry, in the arts, and particularly in hospitals. One sees the world community, in service areas of differing degrees of crowding and sophistication, becoming increasingly water-conscious and accustomed to an ever more complex supply system in which the quality as well as the quantity of water will be adjusted to meet diverse and changing needs.

Changes in Household Habits of Water Use

While the total American water bill for all purposes is necessarily paid by the American consumer, very little of the water load is debited directly to his account; yet this personal fraction of 1 to 5 percent profoundly influences his quarterly water bills and thus his location and habits. As good water becomes expensive, his manner of using it will change; where it becomes more available, his choice of residence will widen. I look for changes in methods of water use at least as early in the home as in industry, and I think the changes will be drastic.

Household water is needed for consumption (eating, drinking, watering gardens, and so on), for cleansing, and for mechanical flushing of solids to the drain. No early modification of the flush toilet is contemplated; the usual requirement of 3 gallons per unit operation is likely to continue. The kitchen disposal unit is quite another matter. To send coffee grounds and banana peel on the crest of a flood to the main sewer is an extravagant use of water, not to mention the business it provides for the unplugger of drains and his interesting rotary equipment. No, the future disposal unit will have, I think, a disposable perforated filter which can be lifted out and thrown in the incinerator or eliminated by some ingenuity as yet undreamed of. The mechanical dishwasher, even more wasteful of water in proportion to the service it performs, requires redesign. The succession of rinse waters should be saved, in serial order, and recycled in later usages of the machine. The same thing applies to the washing machine. The second rinse water from one batch of clothes could become the first rinse for the next batch and the primary wash water for the third. And then there is the question of waste water from the bath and powder-room basin and the surprising quantity that is drawn at the kitchen sink for trivial purposes. Should there be a vat in the basement for all this, and a sump pump for sending it to the toilet tanks or watering the lawn? Should there be a monitor on each drain, perhaps a photoelectric-conductivity hybrid that would switch gates when the water is "good enough" to be saved? Of one thing I am unhappily certain: the 30- to 50-gallon bath is on the way out. Even the shower is due for curtailment. A number of years ago, shocked by the extravagances of the photographic sink, where a little hypo in a few films or prints is washed away with 100 or 1000 gallons of water, the large quantity being needed to keep the prints swirling and apart, I experimented *(34)* to see how little water could be used. A print was suspended, level, by pins in two corners and it was exposed on both sides to mist sprays of the kind used in florists' cabinets. Total consumption, 1 pint, 3 ounces, *and* a better, more evenly washed photograph!

For your shower bath, in 1975, you may stand on an absorbent foam mat on your bedroom floor and pull down a plastic tent from the ceiling. A blast of hot air will blow in an electrified mist which will be attracted to your person in an even layer from top to toe, and for an extra 5 cents you can have, if not a spray wax, at least a toner of perfume or hormone or fertility depressant. You won't need a towel. Later you will put the floor mat through the wringer and use the squeezings to water the potted palm. Science fiction? Perhaps, but a precursor of science fact.

In closing, I will play with the question so often asked those of us who work in this field: What is the up-and-coming conversion process? At the present stage, this is anybody's guess. There is, however, a point that seems to have been missed, and this concerns unit size. The present emphasis is on multimillion-gallon-a-day plants designed to fill the needs of large integrated areas. Many—perhaps most—water needs remain local and scattered beyond the reach of collective supply. It is here, I believe, that the greatest service can be rendered by, and the widest market found for, the packaged unit, to provide potable water where it is lacking, and, to a smaller extent, the mobile unit, to rehabilitate water where it runs, in areas of flood and pestilence. It was notable at a recent international meeting in Washington that the Russian delegates put the immediate needs of the U.S.S.R. *(35)* at four to six very large plants and 20,000 smaller units. Should not the needs for the continental United States be viewed in much the same terms? Such indeed is my opinion.

References and Notes

1. R. Colas, *Dechema Monograph.* **47**, 5 (1962).
2. R. S. Silver, *Proc. Inst. Mech. Engrs. London* **179**, 146 (1964–65).
3. E. A. Ackerman and G. O. G. Löf, *Technology in American Water Development* (Resources for the Future, Inc., Washington, D.C., 1957), vol. 1, p. 23 ff.
4. W. S. Gillam and W. H. McCoy, in *Principles of Desalination*, K. S. Spiegler, Ed. (Academic Press, New York, 1966), p. 2.
5. R. J. Faust, *J. Amer. Water Works Ass.* **58**, 3 (1966).
6. New York Water Authority data.
7. Calculated from data given by G. O. G. Löf, in *Principles of Desalination*, K. S. Spiegler, Ed. (Academic Press, New York, 1966), p. 186.
8. I was a guest of Mr. A. Thorsteinsson and the Mayor of Westman Island in June 1951.
9. G. D. Dickason, personal communication after a visit to Jamaica.
10. Congressional committee hearings on water pollution, Rochester, N.Y., 29–30 July 1966.
11. L. Koenig, *J. Amer. Water Works Ass.* **51**, 845 (1959); ———, in *Principles of Desalination*, K. S. Spiegler, Ed. (Academic Press, New York, 1966), pp. 515–50.
12. Sir William Hudson, *Nature* **195**, 11 (1962).
13. "The Snowy Mountains Story," *Snowy Mountains Authority, Cooma, New South Wales, Publ.* (1961).
14. The Los Angeles Aqueduct, 233 miles long, was finished in 1913; the Colorado River Aqueduct, 108 miles long, was finished in 1936.
15. R. A. Nadeau, *The Water Seekers* (Doubleday, New York, 1950).
16. P. H. Abelson, *Science* **147**, 113 (1965).
17. G. S. Benton, R. T. Blackburn, V. O. Snead, *Trans. Amer. Geophys. Union* **21**, 61 (1950). Also *U.S. Dept. Agr. Tech. Bull. 589* (1937).
18. "First Annual Report, Saline Water Conversion Demonstration Plant, Webster, South Dakota," *Office Saline Water Res. Develop. Progr. Rep. No. 101* (1964).
19. L. H. Shaffer and M. S. Mintz, in *Principles of Desalination*, K. S. Spiegler, Ed. (Academic Press, New York, 1966), p. 281.
20. A. Delyannis and E. Piperoglou, Proceedings of the 1st International Symposium on Water Desalination, Washington, D.C. 1965.
21. G. W. Murphy, *Office Saline Water Progr. Rep. No. 9* (1956); R. E. Evans, G. L. Crellin, M. Tribus, in *Principles of Desalination*, K. S. Spiegler, Ed. (Academic Press, New York, 1966), p. 21 ff.
22. K. Hickman, *Ind. Eng. Chem.* **48**, 7A (1956).
23. M. H. Ali El-Saie, Proceedings of the 1st International Symposium on Water Desalination, Washington, D.C., 1965.
24. F. Van Berkel, J. Van Hassett, J. Van de Torren, *ibid.*
25. "Fourth Annual Report Saline Water Conversion Demonstration Plant No. 1" *Office Saline Water Progr. Rep. No. 171* (1966).
26. L. A. Bromley, in *Univ. Calif. Saline Water Conversion Rep.* (1965).
27. C. E. Ennis, Proceedings of the 1st International Symposium on Water Desalination, Washington, D.C., 1965.
28. R. V. Kleinschmidt, U.S. patent No. 2,185,595; K. Hickman, U.S. patent No. 2,734,023.
29. A. J. Barduhn, Proceedings of the 1st International Symposium on Water Desalination, Washington, D.C., 1965.
30. H. F. Wiegandt, *Office Saline Water Res. Develop. Progr. Rep. No. 41* (1961).
31. I. Villentchuk, Proceedings of the 1st International Symposium on Water Desalination, Washington, D.C., 1965.
32. See reference to Colt Industries, quoted in *Principles of Desalination*, K. S. Spiegler, Ed. (Academic Press, New York, 1966), p. 327.
33. K. Hickman, *J. Amer. Water Works Ass.* **55**, 1120 (1963).
34. ———, *Photographic J.* **1924**, 1 (Nov. 1924).
35. S. I. Golub, V. B. Chernozubov, Ye. A. Sobolev, M. G. Weissblatt, Proceedings of the 1st International Symposium on Water Desalination, Washington, D.C., 1965.