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STATUS OF WASTE HEAT UTILIZATION AND DUAL-PURPOSE PLANT PROJECTS*+

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INTRODUCTION

Ways to conserve energy are being sought all over the United States. Every Btu of heat saved not only extends our fuel supplies but also results in a proportionate reduction in the waste products of fuel consumption — that is, a reduction of atmospheric and thermal pollution.

One method for conserving energy is to use heat which has been discharged from some conversion mechanism or industrial process. There is an abundance of such heat available, often at very low cost and usually in the 60 to 80°F temperature range (for example from steam electric stations), but occasionally temperatures as high as several hundred degrees (e.g. engine and turbine exhausts) may be available.

Several papers[1–4] have been written proposing ways in which low-temperature heat could be used for space conditioning, especially conditioning of agricultural enclosures, such as greenhouses, poultry houses, pig parlors, or in fish farms. These uses utilize the fact that plants and animals grow better and consume less food when kept at their optimum conditions of temperature and humidity.

Also much has been written[5–6] about dual-purpose power stations which produce both electricity and steam. The latter can be used for heating, saltwater distillation, or other processes.

Although the incentives to use discarded heat are numerous, there are also disincentives for such use. These include the necessity of locating the user near the heat source, the potential interruptable nature of the service, the possibility of chemical or radioactive contamination, and seasonable variations in source temperature. It is the purpose of this paper to report the status of several pioneering projects which have been initiated to demonstrate ways in which once-used heat can be substituted for heat from fossil fuels. The authors have made a recent survey of the organizations sponsoring the projects involved and have attempted to obtain the latest information on the status of each project.

Waste Heat Utilization

We define waste heat as heat which is presently being discarded from heat engines, air conditioning and industrial processes. Although steam power stations discharge the largest quantities [as much as 6000 MW(t) at a single site] of low-temperature heat to waters or to air, there are millions of prime movers (gasoline, diesel and gas turbine), air-conditioning systems and industrial processes which must continually dispose of kilowatt to megawatt quantities.

Such thermal effluents have several characteristics which can affect their potential use. The temperatures of these effluents range from 80 to 140^{o}F during warm months and 60 to 80^{o}F in the winter, depending on the type of cooling system being used. The lower temperatures are typical of once-through or run-of-the-river cooling. Condenser water temperatures associated with wet cooling towers are higher, approximately 70 to 80^{o}F in winter and 80 to 130^{o}F in summer. Dry cooling towers, although not yet commonly used, will operate at even higher temperatures, and gas turbine or diesel stack exhausts are at 300 to 400^{o}F. Agricultural and aquacultural applications are best suited to warm water effluents. Some waters (e.g., wet cooling tower circuits and blowdown streams) are heavily treated with chemicals and cannot be allowed to come in direct contact with plants or animals being cultivated. Also, water from nuclear power plants could possibly be contaminated and would have to be monitored. In either case, an exchange of heat may be necessary with the attendant increase in capital and operating costs.

AGRICULTURAL APPLICATIONS

One of the early applications recognized for warm water was to heat greenhouses, and a number of experiments (see Table 1) have been undertaken to demonstrate the feasibility of practicing enclosed agriculture with warm water as the heat source.

Table 1. Warm Water Utilization Efforts in the USA – Agriculture.

Organization	Source of Warm Water	Program or Product
University of Arizona Abu Dhabi and Puerto Penasco	Diesel Generators	Greenhouse Vegetables
Eugene (Oregon) Water & Electric Board	Weyerhaeuser Paper Company Springfield, Oregon	Enhancement of Fruit and Vegetable Production
Tennessee Valley Authority	Present: Electrically Heated Future: Browns Ferry Plant	Greenhouse Vegetables
University of Minnesota and Northern States Power Company	Northern States Power Co. Sherburne County Plant	Greenhouse Vegetables (Proposed)

University of Arizona

The first efforts to heat greenhouses with warm water were by the group under Carl N. Hodges at the University of Arizona Environmental Research Laboratory. They developed a system for transferring heat from water to air in a packed cooling tower and demonstrated conclusively in experiments at Puerto Penasco, Mexico, that vegetables could be grown successfully in the high humidity atmosphere of greenhouses heated and cooled in this fashion.

In 1968, they began construction of a five-acre range of plastic greenhouses for Shaikh·Zayed, ruler of the small sheikdom of Abu Dhabi on the Persian Gulf.[7] The project is now complete and has been in operation since 1972 (see Figs. 1–2). The Abu Dhabi facility has produced 15 kinds of greenhouse vegetables in quantities averaging about 2000 pounds per day. Cucumbers, tomatoes, and lettuce constitute the majority of the production, but eggplant, okra, radishes, turnips, and cabbage are also harvested. The operation is now being performed entirely by Abu Dhabians who are trained by the University of Arizona group and the operation is judged to be completely successful. Diesel generators provide several hundred kilowatts of electrical capacity, and condensate recovery from the evaporated seawater produces drinking water for the fishing villages nearby as well as for the greenhouse crops.

More recently the Arizona group has built a "vegetable factory" for Environmental Farms, Inc.,[8] a subsidiary of the Superior Oil Company of Houston. Ten acres of plastic-covered greenhouses have been installed near the Tucson International Airport and are producing tomatoes at a rate of 3 million pounds per year (see Fig. 3). Although this present installation is not heated with warm water, the system is adaptable to warm water sources if they are available and needed. The project cost one and a half million dollars.

ORNL System — Tennessee Valley Authority

In 1968, the Oak Ridge National Laboratory did a conceptual design study[9] of a vegetable, poultry, and pork food complex for the Fort St. Vrain Gas-Cooled Reactor being built by the Gulf General Atomic Company near Denver for the Colorado Public Service Company. The concept (Fig. 4)

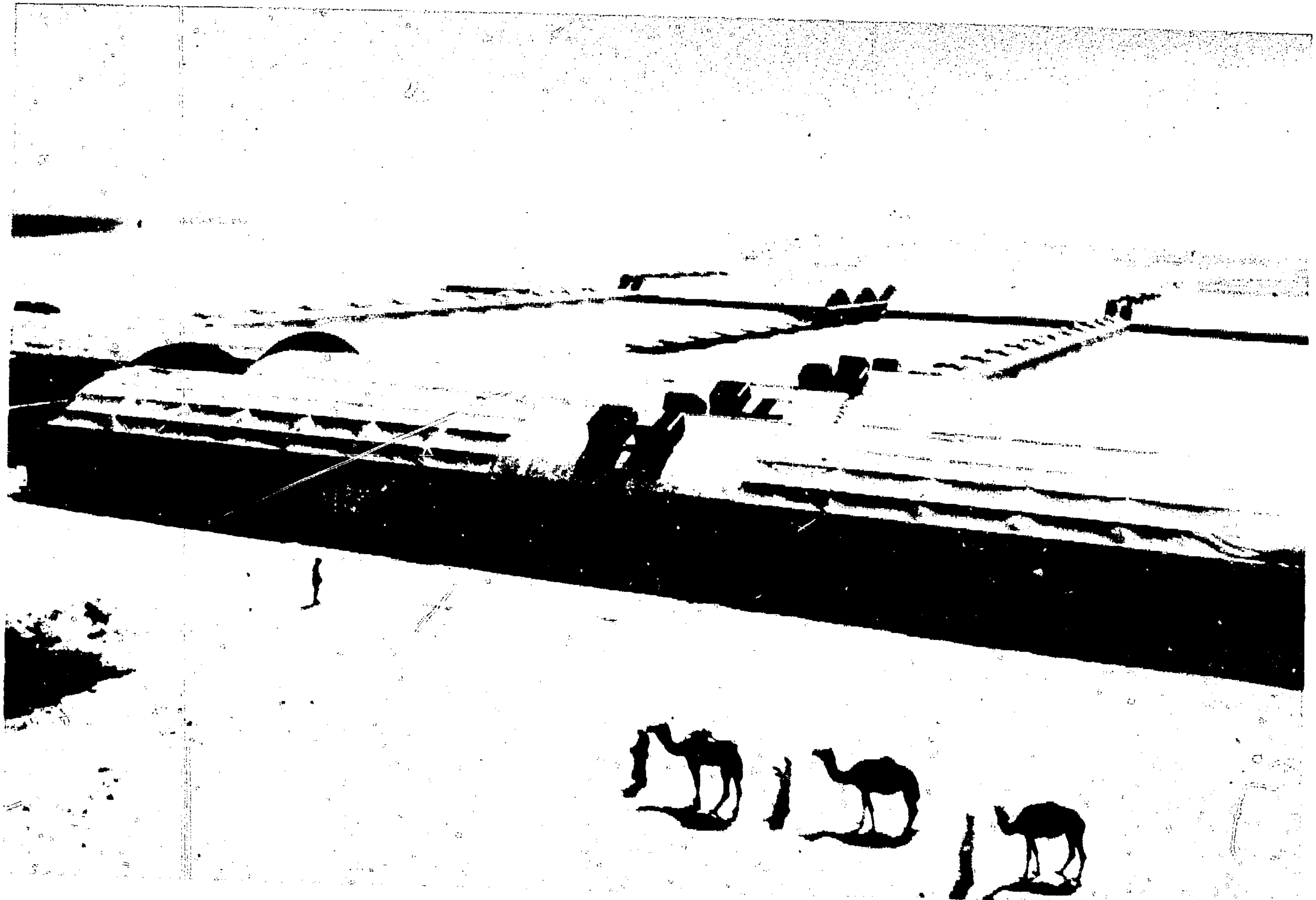

Fig. 1. Sadiyat natives walk their camels past the new controlled environment greenhouses on their island. (Environmental Research Laboratory, University of Arizona, photograph)

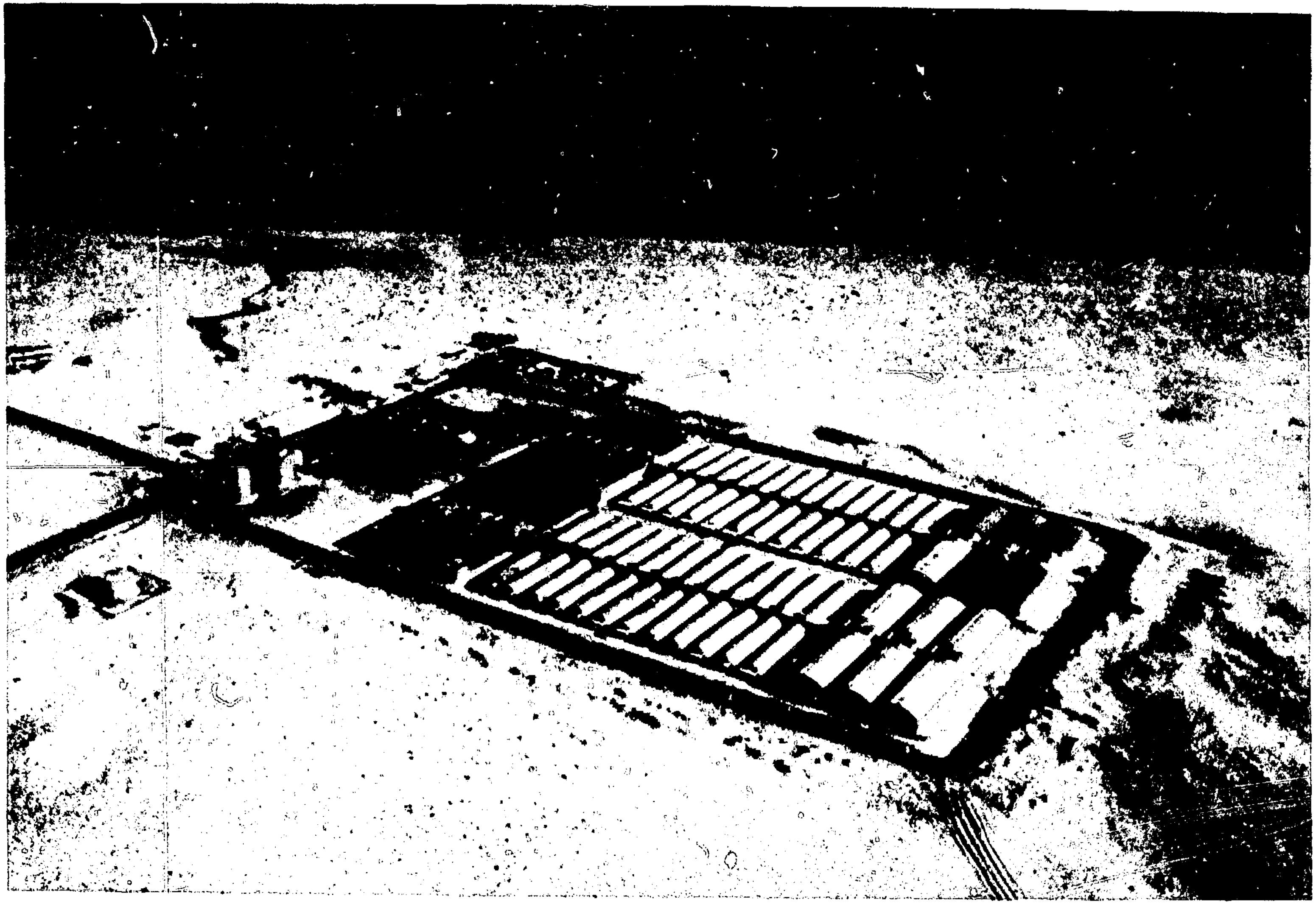

Fig. 2. Half of greenhouses at Abu Dhabi are air inflated (in center) and the remainder are structured enclosures. (Environmental Research Laboratory, University of Arizona, photograph)

Fig. 3. A 10-acre fiberglass and plastic greenhouse complex spreads across the Arizona desert. (Environmental Research Laboratory, University of Arizona, photograph)

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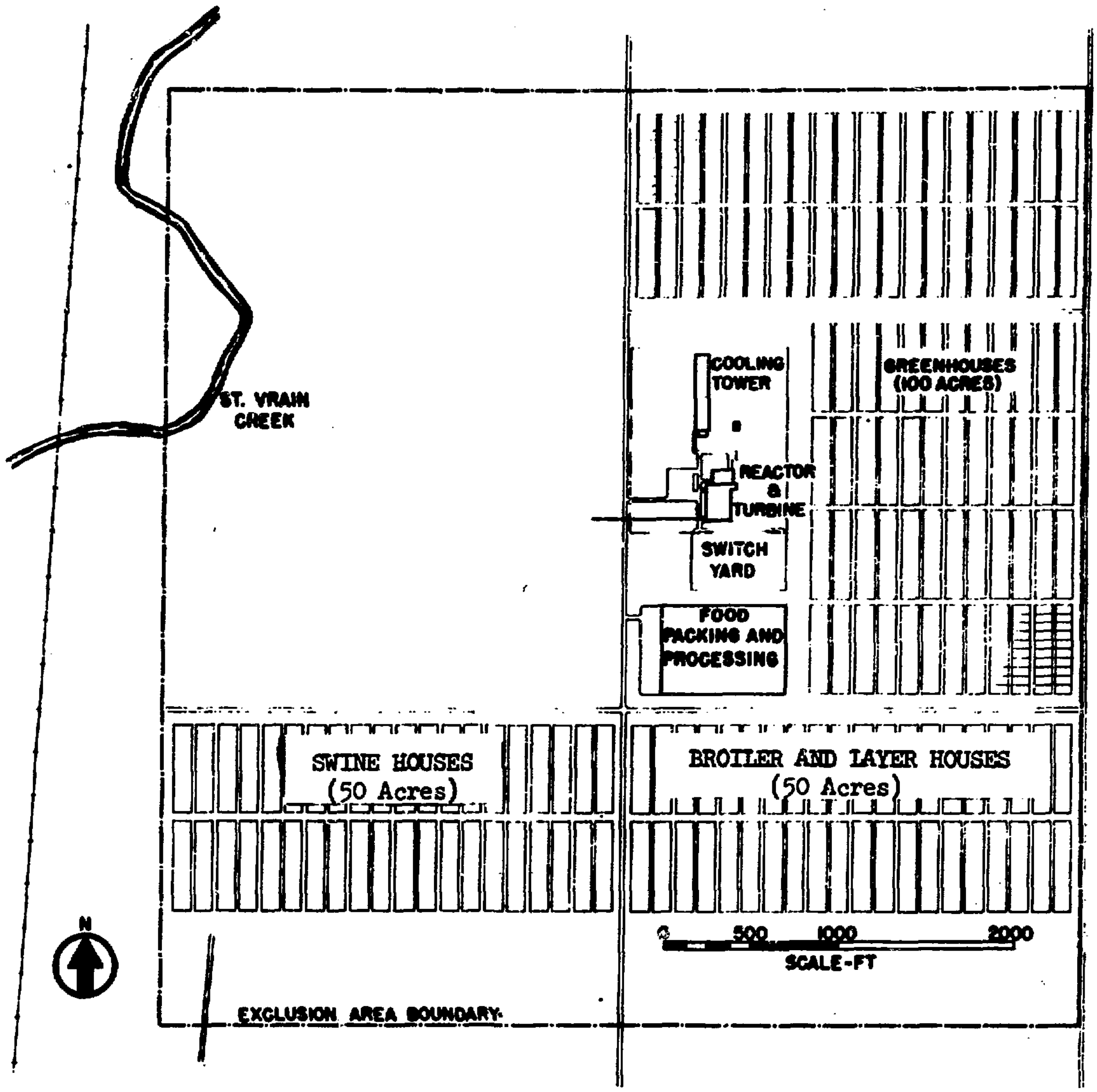

Fig. 4. Possible layout of food production complex at Fort St. Vrain site.

was based on a system of heat transfer which used the evaporative pads normally used for cooling greenhouses. The idea simply was to run hot water on these evaporative pads and to transfer heat from the warm water on the pads to the air passing through them by sensible heat exchange in the wintertime and to use the pads normally as evaporative coolers in the summertime. The design concept is shown in Fig. 5. Note the evaporative pads and a bank of finned tubes at one end. The finned tubes are included to provide enough dry heat to keep the relative humidity of the exit air below 85%, and could be eliminated if humidities >95% are acceptable in the chosen application. Warm water flows first through the finned tubes and then onto the pads. The attic is provided to recycle the air in winter to avoid the need for large flows of cold outside air. In summer, the fans exhaust directly outside and the system operates much as a wet cooling tower.

A proof-of-principle experiment was funded by the AEC at ORNL in 1970 (Fig. 6), and it demonstrated that this idea was sound.[10] The Tennessee Valley Authority decided to use the ORNL concept as the basis for an experiment in vegetable culture at their Muscle Shoals, Alabama, Agricultural Development Station. TVA's pilot greenhouse for waste heat research has now been completed (Fig. 7) and plants have been set for the winter season (Fig. 8). TVA plans several types of heating systems in addition to the one designed by ORNL, and will be experimenting with root media heating by warm water. Depending on the success of this 25 x 100 ft greenhouse experiment, TVA will decide whether to develop the 100 acres of land set aside for this type of agriculture at the Browns Ferry, Alabama, nuclear plant.

Northern States Power Company

The University of Minnesota and the Northern States Power Company are proposing to construct a one-acre enclosed greenhouse at the Sherburne County Generating Plant now under construction near Becker, Minnesota. This plant is to be a fossil-fired unit of some 1400 MW, using a closed cycle condenser cooling system which will result in water temperatures at the condenser of between 85 and 115°F.

The heating system proposed will be basically the same as that employed in the Oak Ridge—TVA pilot research greenhouse at Muscle Shoals. They plan to use inflated plastic structures (100 ft x 250 ft) constructed

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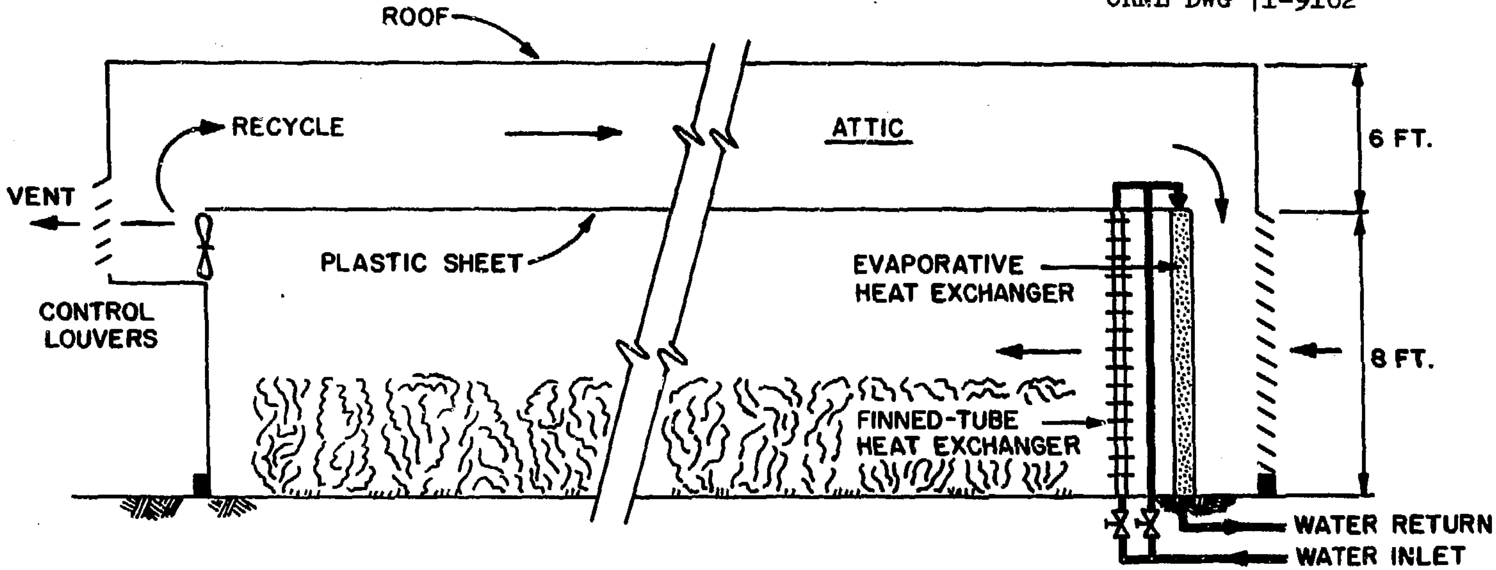

Fig. 5. Typical greenhouse with air and water flow system.

Fig. 6. Interior of the ORNL experimental greenhouse showing the finned-tube heat exchanger. The pads are behind the finned tubes.

Fig. 7. TVA's pilot greenhouse for waste heat research. (Tennessee Valley Authority photograph)

Fig. 8. Plants set for the winter season. (Tennessee Valley Authority photograph)

by Environmental Structures of Ohio. These units have a rigid support and double walled plastic sheets with an air space maintained between the double walls.

At the present time funding for this joint venture of the University of Minnesota and Northern States Power has not been approved.

Other Greenhouse Experiments

In the U.S.A.

Niagara Mohawk – The State of New York and the State University of New York at Albany conducted a small greenhouse heating experiment in 1970-71, and grew vegetable plants successfully.[11] Their heat exchange system employed soil heating pipes and warm water sprayed through metal screens into an air-to-water-droplet heat exchange chamber.

Duke Power Company – The Duke Power Company began an experiment in 1971 to determine if a greenhouse could be satisfactorily heated by flowing warm water over the roof of the house. Although the press of other problems has delayed definitive research, they were able to demonstrate technical feasibility.[12]

Outside the U.S.A.

Probably the largest greenhouse range in the world is at Ploesti, Romania. It now occupies 325 acres, all under glass. The complex consumes 400 MW of heat at maximum heat load which is supplied by hot water (195 to 300°F) from a dual-purpose power station four miles away. The station is designed so that intermediate pressure steam can be bled from the turbine to a heat exchanger when the greenhouse demands hot water.

This greenhouse complex has been in operation for several years supplying cucumbers, tomatoes, eggplant, and lettuce to Romania and for export to nearby countries.[13]

In Italy, Japan, and Iceland, warm-to-hot ground waters are being pumped through underground pipes and water-to-air heat exchangers to heat vegetable and floral greenhouses.

OUTDOOR AGRICULTURE WITH WARM WATER

Eugene (Oregon) Power & Water Board

When the Eugene (Oregon) Power and Water Board chose a site on the McKenzie River for its first nuclear station, it immediately began a program to study the possibilities of using warm discharge water for irrigation and frost protection purposes in that area. Through the cooperation of seven farmers owning land in that area, Oregon State University, Vitro Company, and the Weyerhaeuser Paper Company up-river from the experimental site, this forward-looking power company set up a demonstration project.[14] Water at approximately 130°F was piped from the Weyerhaeuser plant and distributed throughout the acreage owned by the seven participating farmers. Figure 9 shows the layout of this acreage and the crops planted for the experiments. These plots have been cultivated with warm-water irrigation for three seasons, and the results have been exceptionally good. Three important points have been demonstrated: 1) that warm water sprays can provide sufficient frost protection to permit earlier summer harvests and later fall harvests, 2) special pruning is required to prevent ice damage in subfreezing weather, and 3) the effects of soil heating in the root zone appear to be very beneficial for increased yields and better produce. Several varieties of fruit (Fig. 10), vegetables (Fig. 11), and nuts have benefited from this type of irrigation. During the past year the experiments were extended by covering a portion of the acreage with plastic greenhouses (Fig. 12) with warm water distributed through soil pipes. Above-freezing temperatures were maintained within the plastic greenhouses even through the rather severe winter months, permitting certain crops, such as lettuce, to be grown when land would have been unused under normal circumstances. This demonstration is now complete and a final report will soon be published. Although the site will not be used for a power plant as originally planned, the results of this demonstration are available for use by farmers who have access to a source of warm water.

Similar experiments using electrically heated ground cables and overhead irrigation have been conducted at Oregon State University by Professor Larry Boersma.[15] Results from his experiment on vegetable crops indicate not only large increases in per crop yield but also increases resulting from

APPENDIX II

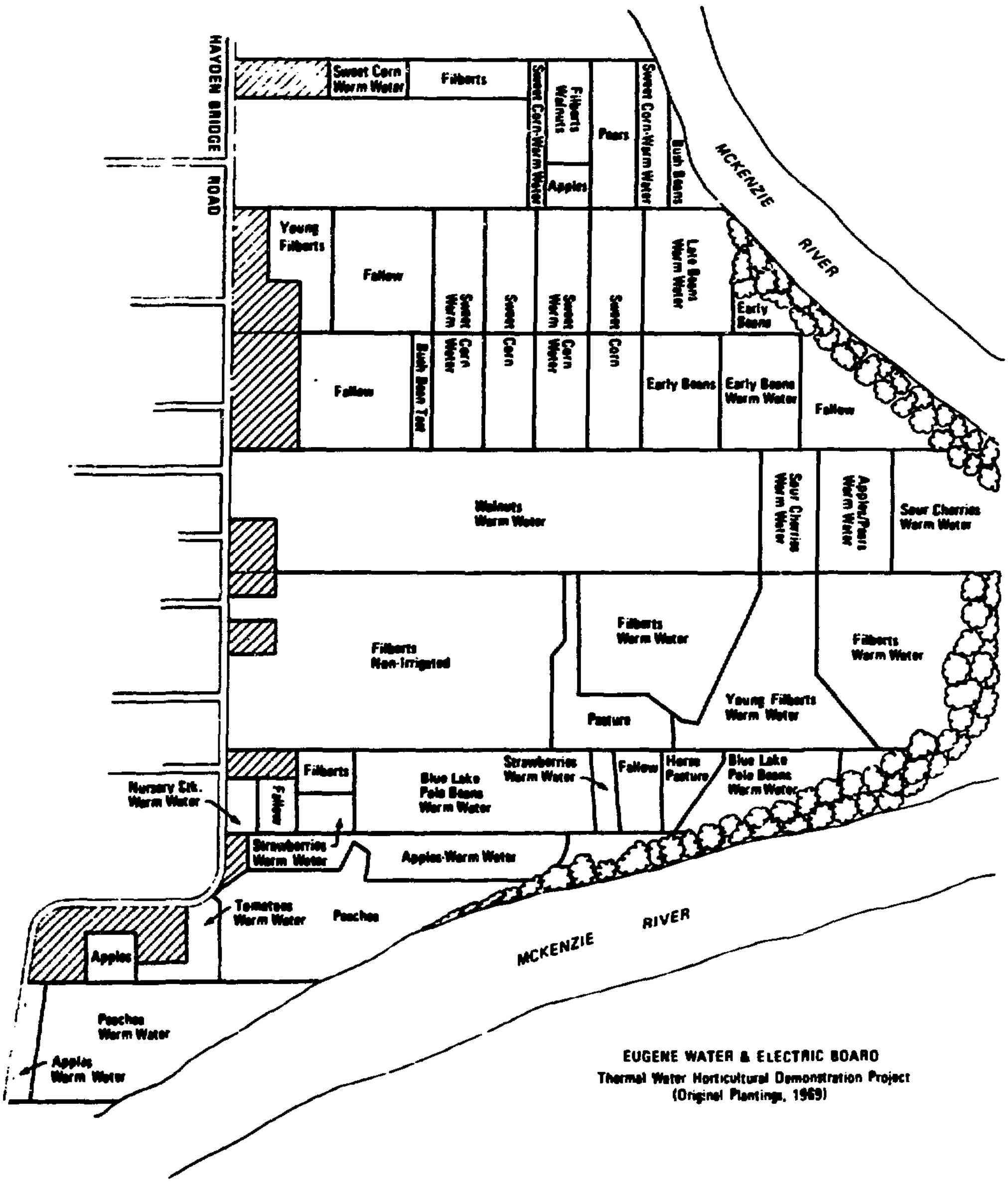

Fig. 9. Thermal Water Horticultural Demonstration Project. (Eugene Water & Electric Board photograph)

Fig. 10. Fruit which has benefited from irrigation. (Eugene Water & Electric Board photograph)

Fig. 11. Vegetable which has benefited from irrigation. (Eugene Water & Electric Board photograph)

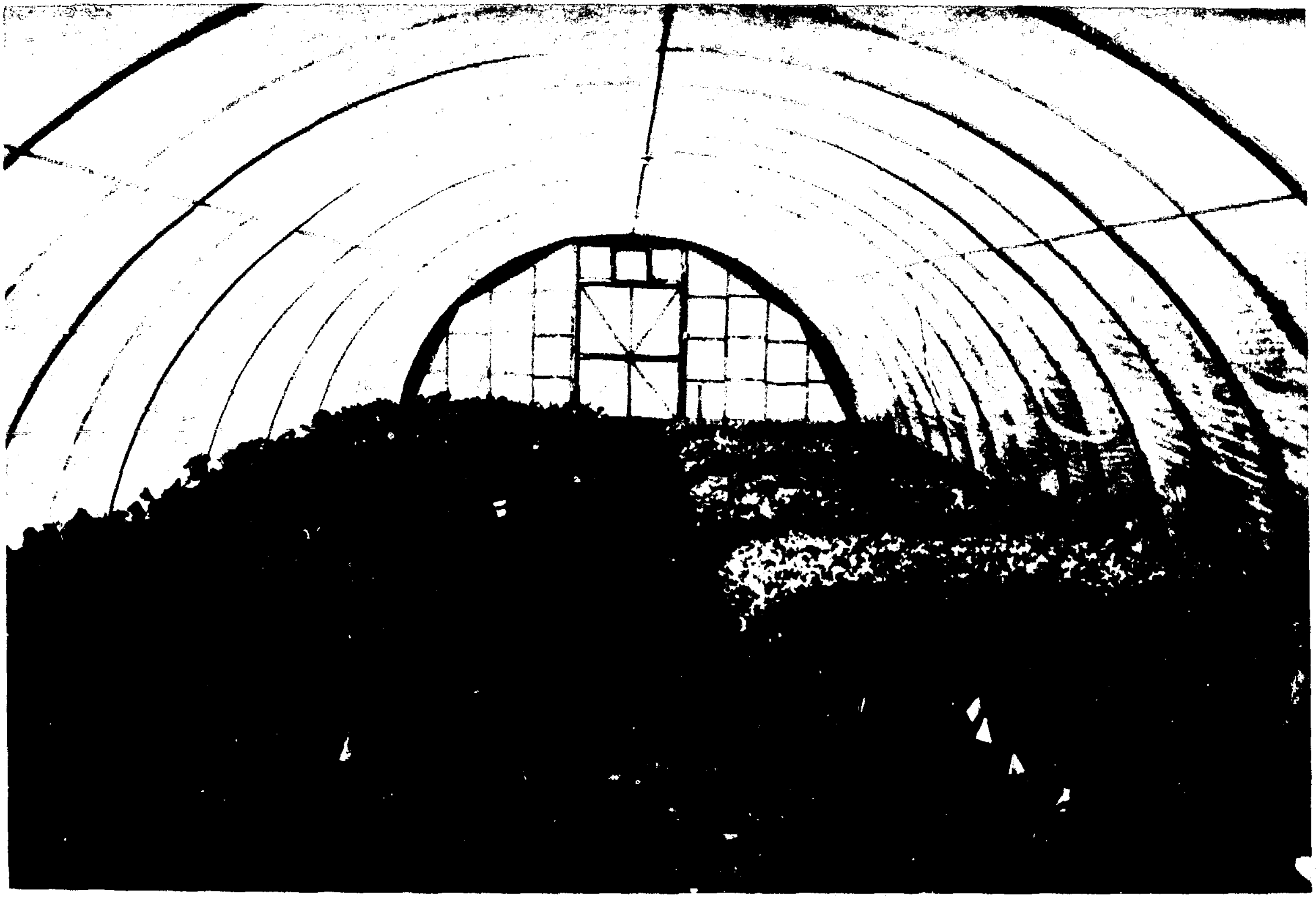

Fig. 12. Portion of acreage with plastic greenhouses, with warm water distributed through soil pipes. (Eugene Water & Electric Board photograph)

two crops where previously with no underground heating only one crop could be grown. An additional clear advantage to the farmer results from being able to reach the fresh vegetable market at least several days to one week ahead of competitors and therefore commanding premium prices for the produce.

AQUACULTURE

The known aquaculture and mariculture operations with heated effluents in the United States are summarized in Table 2.

Cal-Maine Company and Tennessee Valley Authority

The Gallatin Steam Plant, located on the Cumberland River near Gallatin, Tennessee, is a run-on-river fossil-fired facility consisting of four generating units each of approximately 300 MW capacity. The Aquaculture Facility built in 1970 (Fig. 13) is located adjacent to the plant discharge canal and consists of ten concrete channels of four foot square cross-section 50-ft long. Heated discharge water for the channels is drawn from the plant discharge canal and released back to the canal some 30 ft downstream of the intake at a rate of 2,000 gpm. Normal operation allows approximately 200 gpm per channel to flow through the facility.

Hand feeding of the fish is employed, and food is either Purina catfish food or a special trout food.

Although the facility has been operating since the summer of 1970, Cal-Maine recently purchased the facility and TVA began participating in the operation only in May 1972. The first crop of catfish was harvested in 1971, and was the basis for projecting yields of several hundred thousand pounds per acre per year. Unfortunately, in June 1972, a major incident occurred which resulted in the killing of their entire lot of 68,000 pounds of fish. The kill resulted from a fractional interruption of electrical power due to a storm. The interruption caused the electrical contactors operating the circulating water pumps to drop out and, because the check valves on the suction lines to the pumps did not close as they were supposed to, the pumps lost prime. Prime could not be re-established for

Table 2. Warm Water Utilization Efforts in the USA — Aquaculture and Mariculture.

Organization	Source of Warm Water	Program or Product
Ralston Purina Company	Florida Power Corporation Crystal River Station	Salt Water Shrimp Culture
Cal-Maine Company	Tennessee Valley Authority Gallatin Station	Commercial Catfish Production
Inmont Corporation	Long Island Lighting Company Northport Station	Commercial Oyster and Clam Production
Cultured Catfish, Inc.	Texas Electric Service Company Lake Colorado City, Texas	Commercial Catfish Production
International Shellfish Enterprises (ISI)	Pacific Gas and Electric Company Moss Landing, California	Oysters, Clams, Abalone
Kansas Power and Light Company	Hutchison Station	Catfish Experiments
Aquarium Farms, Inc.	City of Fremont, Nebraska Utilities Department	Fresh Water Shrimp, Catfish, Clams

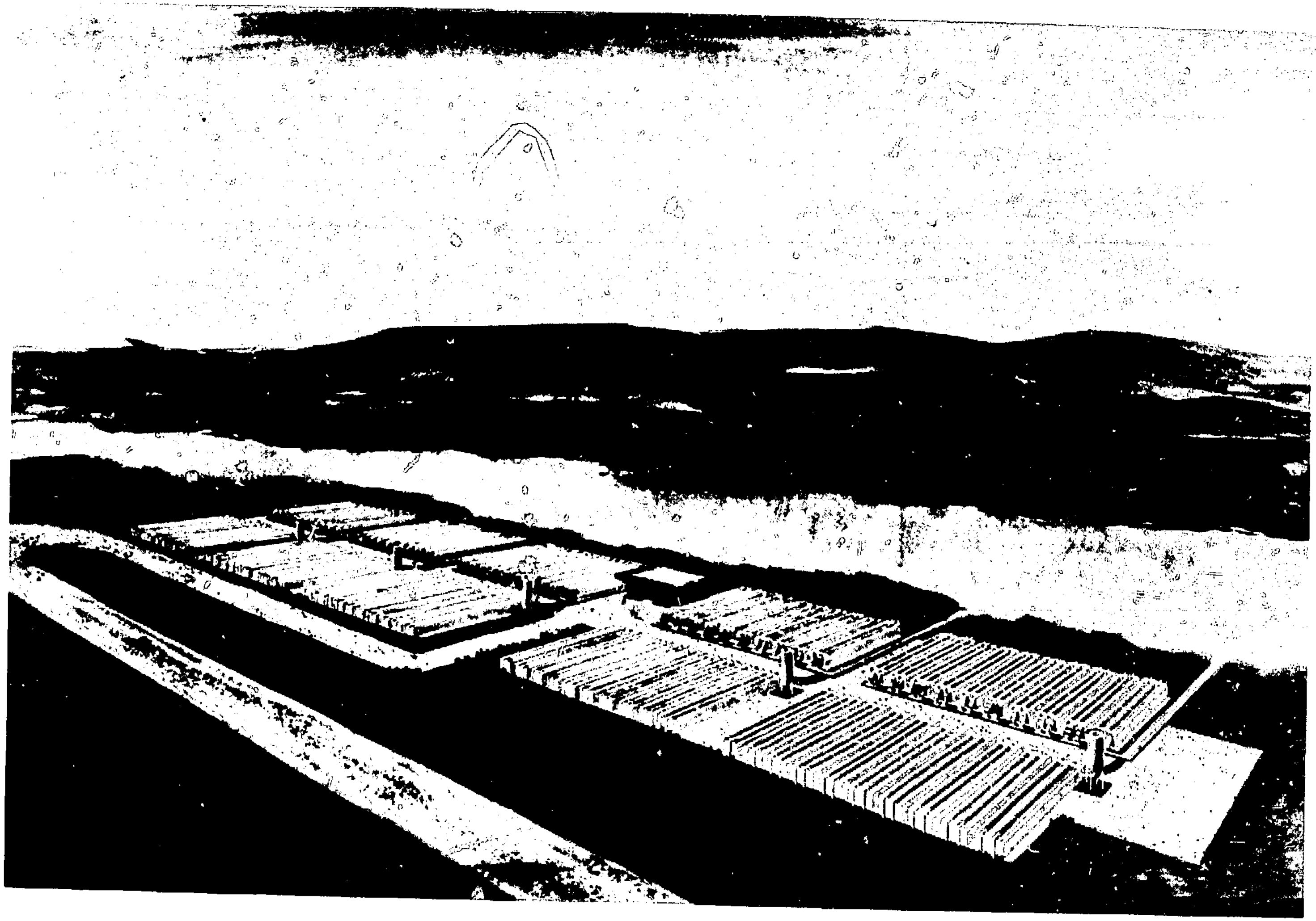

Fig. 13. Artist's concept of a real installation at the Gallatin Steam Plant of TVA. (Photograph by Henry Schofield Studio, Nashville, Tennessee)

several hours because of the faulty back-check valves, and it is believed that the fish-kill was due to oxygen deficiency during the non-flow conditions.

In July 1972, 105,000 fish were stocked into the channels; two channels were stocked with 7500 fish each, four channels with 10,000 fish each, and four channels with 12,500 fish each. It was recognized to be a poor time of year to stock, and the fingerlings purchased are believed to have been infected with epistylus (a protozoa which attaches to the fish as a parasite causing fish mortality). The disease was treated by feeding a 1-1/2% salt solution into the individual channels under either no-flow or very low-flow conditions. A loss of 40% of the stock resulted from the disease.

Recently to improve oxygenation, an aeration system was introduced into the raceways. It consists of five-ft-long modules of plastic tubes with 1/8-in. holes on 8-in. centers. The tubes are imbedded in gravel along the bottom and extend the full length of the channel. It is believed the aeration system will improve the normal dissolved oxygen level in the channels and will also prevent the recurrence of a fish-kill from a no-flow condition. The oxygen level is maintained around 5 to 7 ppm, sometimes as high as 9 ppm, and there is a perceptable drop along the length of the length of the canal.

Water temperatures on a seasonal basis vary from the low 50's in winter to a maximum of approximately 82^{o} in summer at the facility. Thus at no time of year is optimum temperature for catfish (approximately 85^{o}F) actually maintained. Growth rates could be enhanced further were it possible to maintain winter temperatures near the optimum for growth rate.

One of the problems recognized early was that of pollution caused by excess fish feed being swept into the plant discharge canal, and by wastes voided by the fish. TVA and Cal-Maine are now in the process of trying to characterize the waste leaving the Aquaculture Facility. Daily tests are made to determine the water quality leaving the facility. Soluble phosphates, pH, dissolved oxygen, nitrogen series, and other water quality characteristics are measured and correlated with feeding rate, water flow rate, flushing frequency, etc.

This intensive culture experiment is recognized as still requiring development before being commercially feasible. Even so, much progress has been made. During the past year conversion rates of one pound of fish for every 1-1/2 pounds of feed were obtained.[16] Growth rates are much higher than in unheated waters and mortality rates were below 5%.

Cultured Catfish, Inc.

Mr. John Kelley, President of Cultured Catfish, Inc., began growing catfish in the warm water discharged from the Colorado City Station of Texas Electric Service Company in 1969. Production in 1972 was 100,000 pounds of catfish on less than one acre of lake area. The fish are grown in cages at high density. Eventual capacity is projected to be a million pounds per year, according to Mr. John E. Tilton of TESC.[17]

A similar operation is in progress at the Lake Trinidad Station of Texas Power and Light Company. Production there is presently at a rate of 60,000 lb/yr.

Aquarium Farms, Inc.

Another aquaculture operation using discharge waste heat from a power plant is being carried out near the small town of Fremont, Nebraska. Here an organization called Aquarium Farms, Inc.,[18] is currently raising channel catfish in 1200-ft-long raceways which receive 10,000 gpm discharge water ranging in temperature from 73 to 80°F from the Fremont municipal generating plant. Aquarium Farms plan on raising between four and ten million fish (catfish and tilapia) in the present discharge channels which occupy approximately eight acres of land. In addition, they have plans for raising the giant Malaysian fresh-water shrimp and for establishing colonies for mussels and clams.

An indication of the problems involved in such operations occurred this year when Aquarium Farms had plans and market contracts for some 700,000 pounds of catfish. The spring floods which occurred in early 1973 wiped out a good portion of the fingerling stock which are supplied from the lower Mississippi Delta country, and as a result the price of fingerlings increased to record proportions and instead of 700,000 fingerlings as planned, only 250,000 could be obtained. To date, they have been operating with mortality rates of approximately 3% and have no particular problems with oxygen level even though oxygen is supplied only by the natural absorption at the air-water interface.

MARICULTURE

Long Island Oyster Farms

Perhaps the most successful application of waste heat in mariculture is the operation of the Inmont Corporation's Long Island Oyster Farms of Northport, Long Island. This company uses the thermal effluent from the Long Island Lighting Company - Northport plant to enhance growing in the early stages of oyster culture. Normal growing periods of four to six years have been reduced to 2 1/2 to 3 1/2 years by selective breeding, spawning, larva growth, and by seeding the oysters in the hatchery (see Fig. 14) and then placing them in the warmed discharge lagoon of the Northport plant (Fig. 15). The oysters are allowed to remain in the discharge lagoon over a period of four to six months during which time their growth rate can be as much as a factor of five greater than would be the case in the normal ambient temperatures of Long Island Sound. The oyster culture is completed by removing the oysters from the discharge lagoon and placing them in the colder waters at the eastern end of the Sound (Fig. 16). The Long Island operation is now on a commercial basis and sales of approximately 5 million dollars per year are being achieved.

The Long Island Oyster Farms have recently begun raising clams as well as oysters in the heated discharge lagoon. Currently they are raising a million clams a day. Long Island Oyster Farms is also examining the possibilities of raising fresh-water shrimp.[19]

Ralston Purina Company

In 1970 the Florida Power Corporation and Ralston Purina Company formed a joint venture to investigate the possibilities of mariculture using the heated discharge water from the plants of the Florida Power Company located along the Crystal River in Florida. This site contains two fossil fuel generating units with a combined capability of about 900 MW(e). An 825 MW(e) nuclear unit is under construction at that site and an

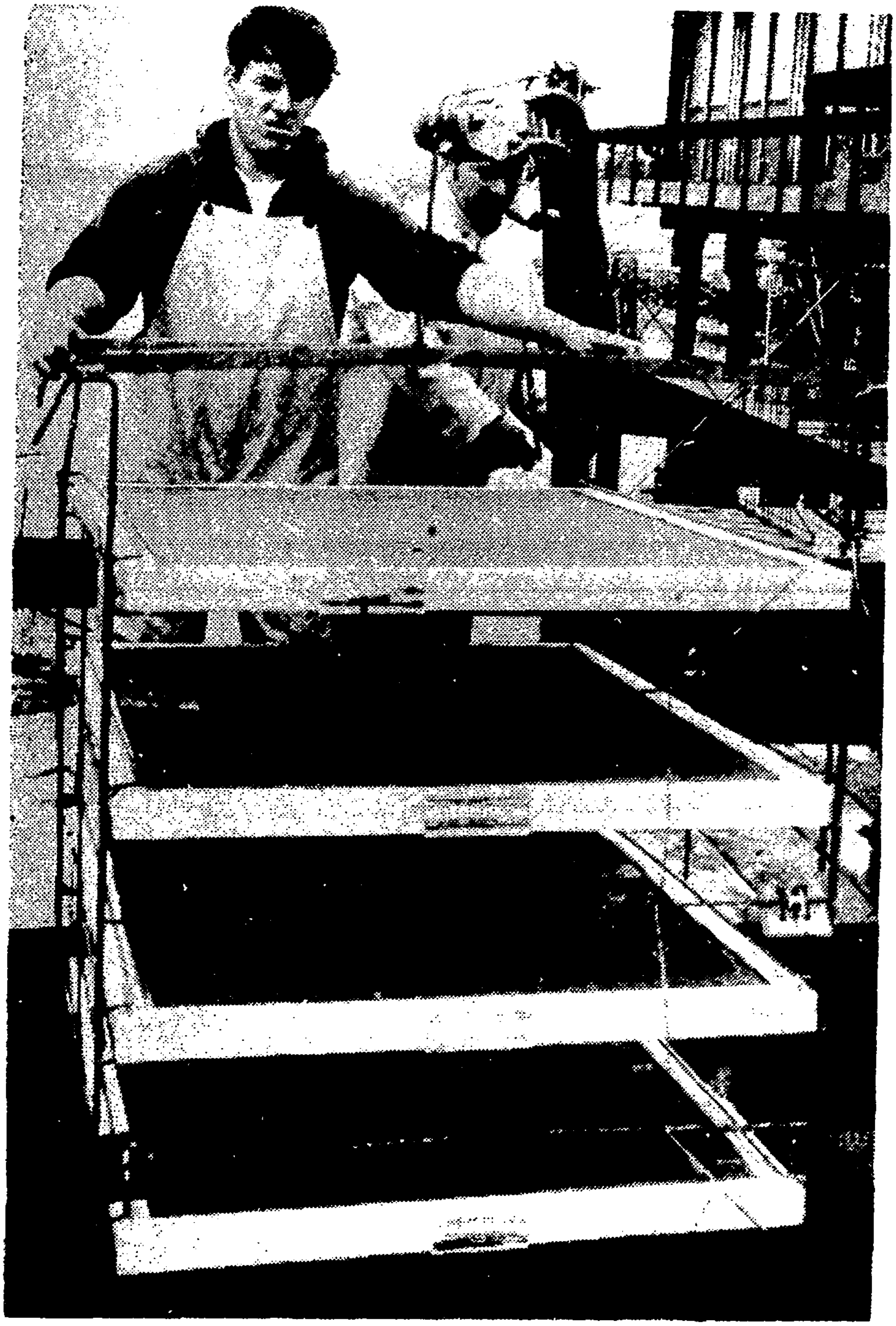

Fig. 14. Trays of juvenile oysters being readied for immersion in Long Island Oyster Farms' warm-water "nursery." (Photograph from Fish Farming Industries, April 1971)

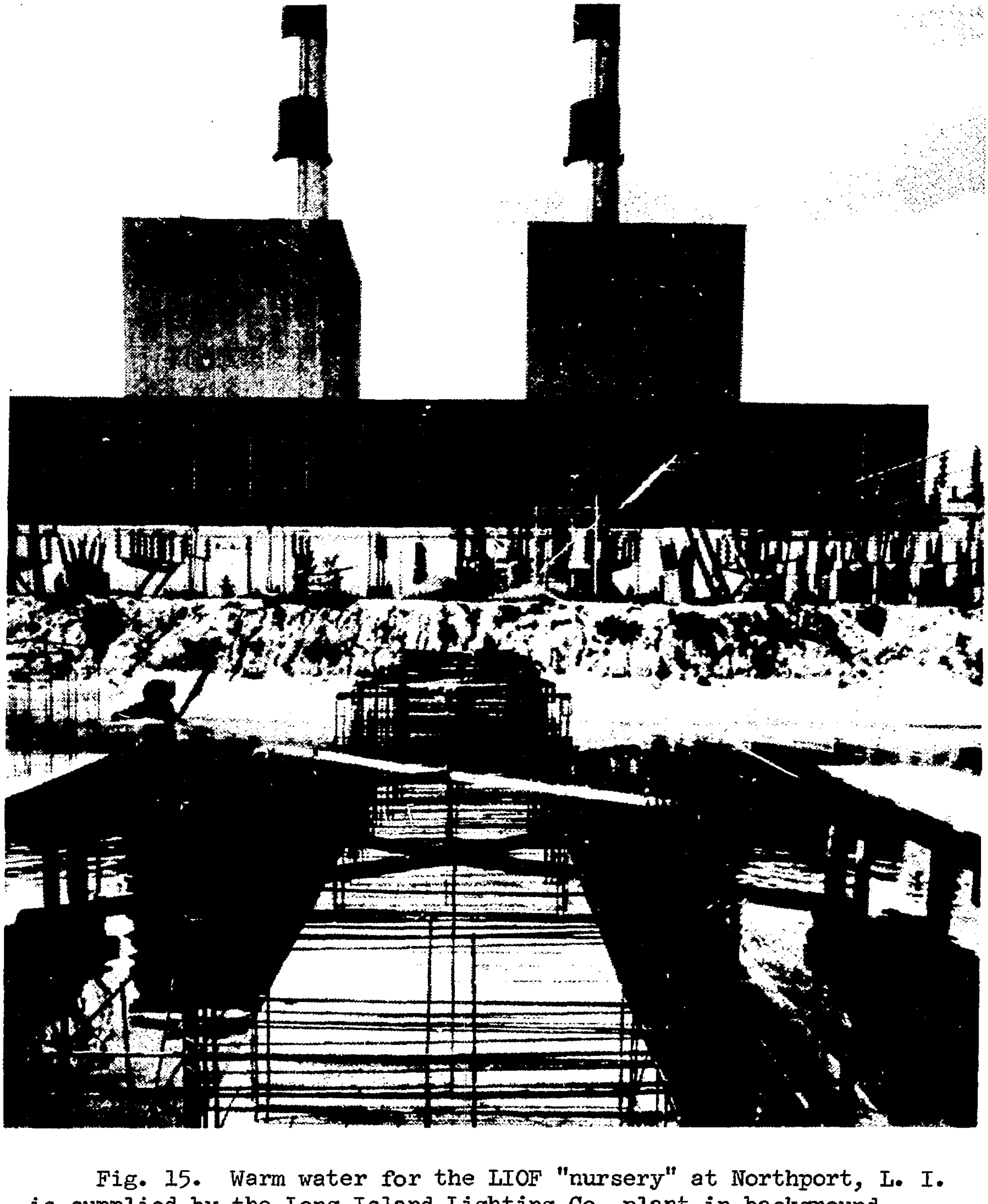

Fig. 15. Warm water for the LIOF "nursery" at Northport, L. I. is supplied by the Long Island Lighting Co. plant in background. (Photograph from Fish Farming Industries, April 1971.

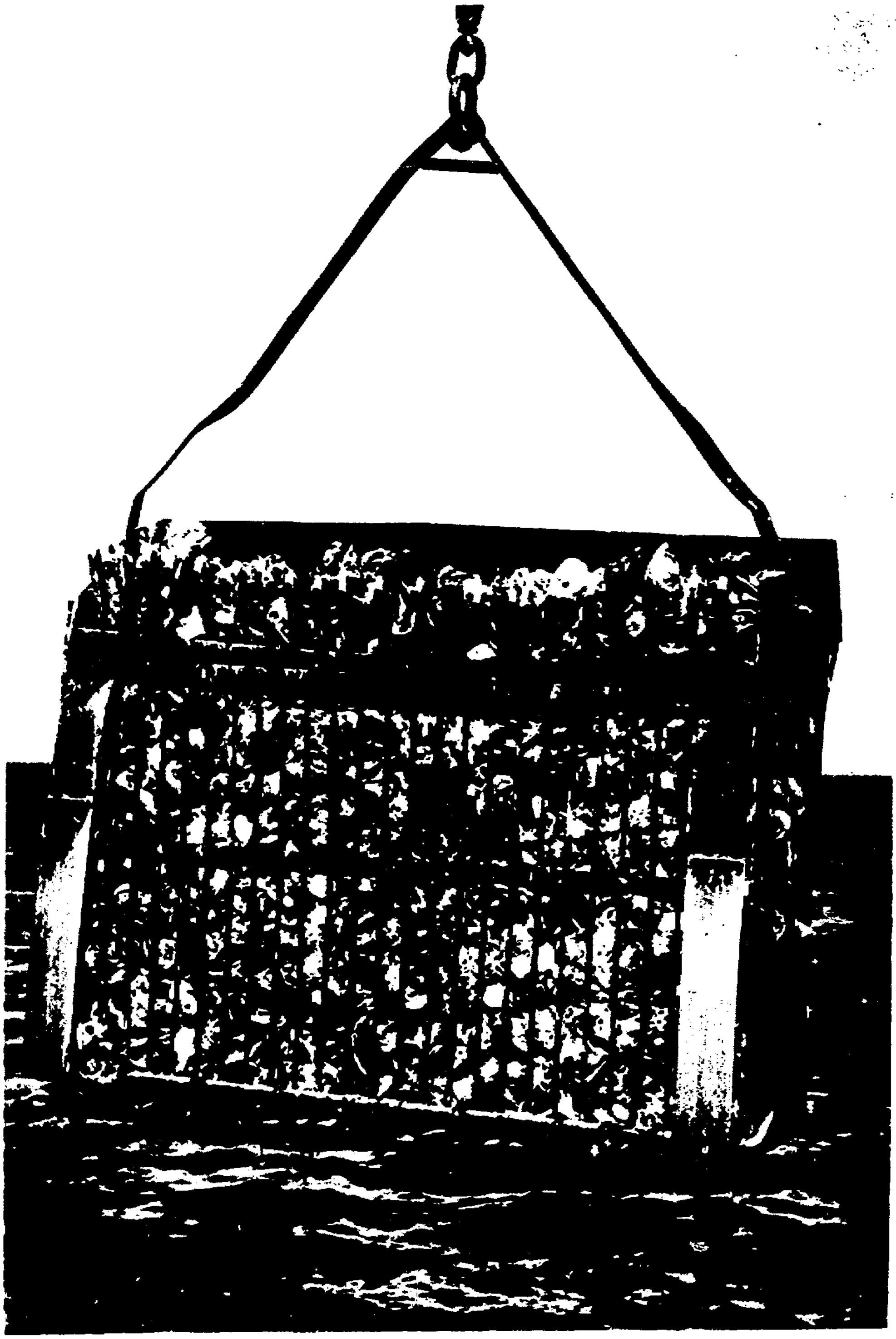

Fig. 16. A dredgeful of fresh LIOF oysters being hoisted aboard one of the company's harvesting boats from the cold, pure waters of Long Island Sound. (Phctograph from Fish Farming Industries, April 1971)

additional 900 MW(e) unit is planned for 1978. Condenser cooling water for the site is obtained from the Gulf of Mexico and brought to the site and discharged via two large canals extending from the site to the Gulf of Mexico. Some 50 acres of land lying between the canals has been designated as a site for a mariculture project. The mariculture site contains a 7000 ft^2 research facility and eight ponds which cover about six acres in area and have the provisions for receiving both warm or ambient temperature water into the ponds. Ralston Purina has general responsibility for operation of the mariculture facility. Research at the facility to date has been devoted to:

1) procurement and identification of species of shrimp conducive to the pond and raceway types of culture,
2) defining the nutritional needs for various species of shrimp and the development of commercially acceptable diets,
3) the identification and control of diseases, and
4) environmental investigations to determine the ideal water quality conditions for growth of shrimp at Crystal River.

Studies to date at Crystal River show that the most efficient growth temperatures for shrimp are in excess of 75°F. These studies also show that temperatures of from 47 to 53°F or less resulted in excessively high mortality or permanently stunted animals. The efficiency of growth, that is pounds of feed to pounds of shrimp produced, was affected significantly by reduced temperatures, as other work has shown. With the two fossil units in operation, length of the growing season for pond shrimp has been extended from the normal 180 days to 225 days. The start of the nuclear unit, Crystal Unit III, should extend the estimated growing season to 300 to 320 days per year, and will allow Purina to grow shrimp almost year round. Before a final decision is made to proceed with a commercial operation, this research phase must be completed.

An interesting facet of this particular program is the detailed agreement reached by Ralston Purina and Florida Power on the respective roles they have in this waste heat program. For example, each company has the right to terminate the project at any time and the obligations for doing so are defined. Termination of the project because of acts of a regulatory agency or acts beyond the control of the company, however, incur no obligation to either company. Ralston Purina has been given responsibility for all the marine science aspects of the project. They also will secure all permits, licenses, government approvals, to operate the project with the assistance of Florida Power. Florida Power in turn has no obligation to modify the operations of its generating facilities nor does it have a liability for adverse effects on the mariculture project from a normal operation of the power plant. Thus, the emphasis is that mariculture activity must adapt to utility operations. Since, however, Florida Power has a significant investment in this project, it, too, has a strong interest toward the success of the effort.

International Shellfish Interprises (ISI)

Since 1969, this west coast company has been experimenting with shellfish cultivation in the heated waters from Pacific Gas and Electric Plant at Moss Landing near Santa Cruz, California. Oysters and clams are hatched and kept for about six months in a warm water nursery (71 to 79°F) before being put into the lagoon for 18 months to complete their growth. Eastern oysters are presently being produced at a rate of one million per year and plans are to reach 10 to 12 x 10^6 oysters per year in several years. ISI has a cooperative program with a Japanese group and expects to use their expertise for commercial production of abalone.[20]

Mariculture in Japan

Although about 20% of Japan's requirements for fish, shellfish, and crustacians are provided by cultivation in the nation's many aquacultural and maricultural facilities, warm water facilities have been developed only in the past few years. As Table 3 shows there are five separate mariculture facilities in operation today using power plant effluents.

As early as 1967, the Tohoku Electric Company supported large-scale experiments with abalone culture at their Sendai Station, and growth rates several times greater than natural growth were measured for thousands of abalone.[21] Sendai water temperatures varied from 64 to 79°F, which is 15°F above ocean ambient temperatures.

Table 3. Warm Water Utilization Efforts in Japan.

Power Company	Station	Program
Hokkaido Electric Power Co.[1]	Ebetsu Takigawa	Greenhouse Vegetables and Eel Culture
Chubu Electric Company[1]	Owase Mita	Yellowtail and Prawn
Kansai Electric Power Company[1]	Tanagawa Himeji	Yellowtail and Prawn
Tohoku Electric Power Company[2]	Sendai	Trout and Abalone
Japan Atomic Power Company[2]	Tokai Tsuruga	Shrimp, Red Snapper, Abalone

Reference 1. Personal communication, K. Masui, Japan IERE Council, October 1973.

2. Personal communication from Japan Science and Technology Agency and Japan Atomic Industrial Forum to M. Nozawa, October 1973.

A large culture program also is in progress at Japan's first nuclear station, the Tokai Reactor Plant of Japan Atomic Power Company (JAPCO). In 1971, a five-year, $1.5 million program of shrimp, red snapper and abalone culture was begun. Twelve ponds (18 ft x 30 ft) are presently in use and 22 additional ponds are being built in 1973. The total pond area will be nearly 1/2 acre.[22]

Growth rates measured for shrimp and snapper are much higher in the 15^{o}F warmer discharge water than at natural temperatures. No radioactive release or contamination has been detected.

JAPCO also is developing a 9000 ft^2 pond area at their Tsurugu Station.

DUAL-PURPOSE PLANTS

Dual-purpose energy plants are those which supply both process heat (or district heat) and electricity from a single source of heat. Usually the heat is removed from the system after the working fluid (e.g., steam) has generated some electricity. For the greatest fuel economy, steam can be extracted from an intermediate stage of the turbine or taken from the turbine exhaust. However, even when bled directly from the boiler there may be a significant cost saving in the overall dual operation. Modern thermal electric stations have thermal efficiencies in the range 32% (light water reactors) to 40% (fossil plants and gas-cooled reactors). Improvements of at least 10 to 20% in overall fuel utilization can result from a combined operation. Such operations could significantly reduce the oil and gas consumption in future years.

Because the costs associated with the transport of heat are high, it is essential that heat users be geographically close to the heat generation source. This requirement suggests that adjacent siting of power plants and industrial plants is a requisite to the furtherance of dual-purpose applications. Industrial users of significant quantities of process steam must be within a few miles of the power plant to avoid high steam delivery costs. Typically, transmission can increase the cost of heat by about two to five cents per million Btu's per mile. Generally, steam below 150 psig is not piped farther than one mile. As energy costs increase, however, these tradeoff distances may change significantly.

The status of several dual-purpose projects is summarized in Table 4.

Table 4. Summary of Dual-Purpose Plants.

Power Plant	Heat Consumer	Quantity	Application
Linden Station (Public Service Electric & Gas of New Jersey) Oil-Fired (460 MWe)	Exxon Refinery and Others	Steam: 1.15×10^6 lb/hr at 150 psig 0.4×10^6 lb/hr at 750 psig	Petroleum Refinery
Louisiana Station (Gulf States Utility Co.) Oil-Fired (300 MWe)	Exxon, Uniroyal, Allied Chemical	Steam: 3.2×10^6 lb/hr (at 135 and 160 psig)	Chemicals and Petroleum Products
Midland Station (Consumers Power Co.) Pressurized Water Reactor (1380 MWe)	Dow Chemical	Steam: 3.6×10^6 lb/hr at 180 psig $.4 \times 10^6$ lb/hr at 675 psig	Chemicals
Tijuana, Mexico [(1)] Municipal Plant Oil-Fired Turbine (75 MWe)	Same	Steam: 2.6×10^6 lb/hr at 12 psig	Distilled Water (7.5×10^6 gal/day)
Shevchenko, USSR BN-350 Breeder Reactor (150 to 350 MWe)	Same	Steam: $10 - 15 \times 10^6$ lb/hr	Distilled Water (32×10^6 gal/day)

1. Representative of 50 dual-purpose desalination plants throughout the world, with combined capacity of 170 MGD.

Public Service Electric and Gas Company - Exxon Refining

One of the best examples of dual-energy plants generating steam used for both electrical power and industrial steam applications is the Linden generating station of Public Service Electric & Gas of New Jersey. This plant supplies 1.15 million pounds of steam per hour at 150 psig and 0.4 million pounds of steam at 750 psig to the Bayway Refinery of Exxon, which is located about 6,000 feet from the Linden boiler house. The station generates about 460 MW(e), some of which is also used by the refinery. Fuel oil from the refinery is fed to the Linden station as part of the arrangement. Initial operation of the dual-power facility began over 15 years' ago.

An indication of the steam and energy flows can be seen on Figs. 17 and 18, showing steam flows and pressures and the gain achieved through operation of the Linden station as a dual-purpose facility. Public Service estimates that operating as a conventional generating station 8800 Btu's of purchased fuel would be required to produce one kilowatt hour of electrical energy. This is equivalent to an overall plant thermal efficiency of about 39%. However, as a dual-purpose facility only 6292 Btu's of purchased fuel (net) are required to produce one kilowatt hour of electrical energy (over and above the fuel required to generate steam) equivalent to an overall fuel efficiency of 54%. Thus the increase in fuel economy from 39 to 54% represents a 38% increase in fuel utilization.

A major problem in dual-plant operation exists in the matching of steam supply with steam demand. For example, Public Service recently completed construction of an additional boiler facility which will be used in power generation and can supply an additional one million pounds of steam per hour to an industrial load. Because of present uncertainties in supplies of crude for the Bayway Refinery, there is a question about the need for additional steam from the Linden station, and the new capacity may not be used by the refinery.[23, 24]

Gulf States Utility Company

Another dual-purpose facility which is achieving over 50% fuel efficiency is the Louisiana Station of Gulf States Utility Company. This plant has nine turbines with a capacity of approximately 300 MW and can supply

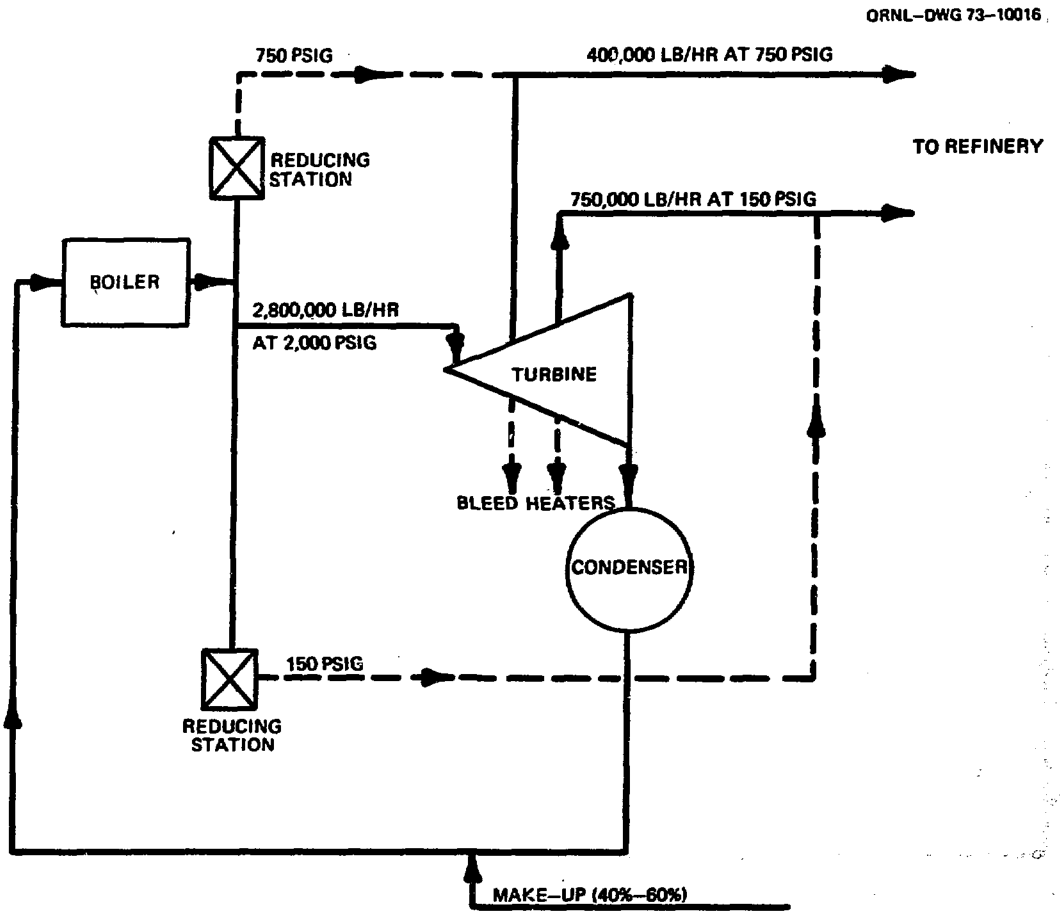

Fig. 17. Steam flow - Unit No. 1, dual-purpose operations as illustrated by the Linden Station. (Courtesy of Public Service Electric and Gas Company of New Jersey)

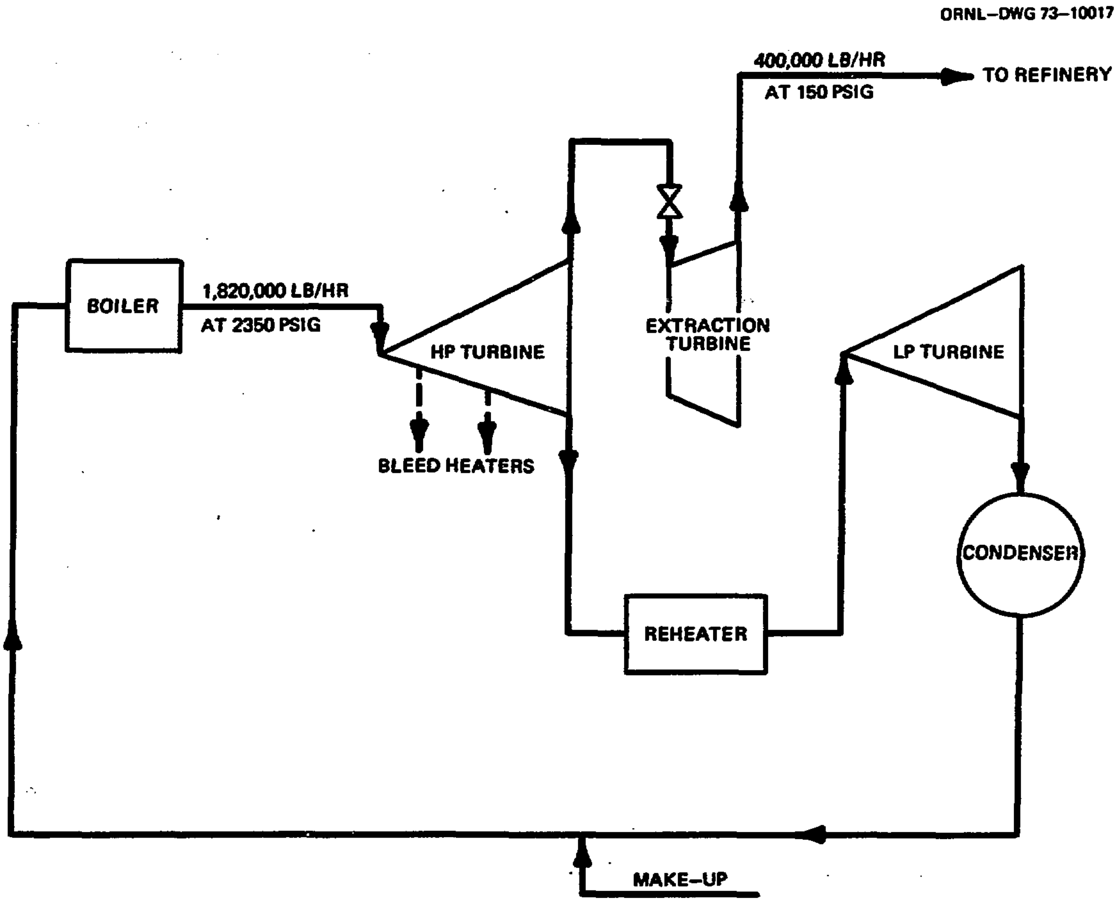

Fig. 18. Steam flow - Unit No. 2, dual-purpose operations as illustrated by the Linden Station. (Courtesy of Public Service Electric and Gas Company of New Jersey)

600 psig and 135 psig steam at a rate of 3.2×10^6 lb/hr. Several of the turbines can operate fully condensing or backpressured to 135 psig. Also, the plant is equipped to provide prime steam throttled to 600 psig and 135 psig when there is no electrical generation.

A complex of chemical companies and refineries is supplied: Exxon (chemicals and refinery) consumes 75% of the output, and the remaining 25% is fed to Ethyl Corporation, Uniroyal and Allied Chemical Company.

Gulf States operates this plant with first priority to the steam customers. The arrangement has proved financially attractive to all parties, as well as highly efficient in fuel use, and has led Gulf States to seek process steam contracts at other planned stations.[25]

Dow Chemical Company – Consumers Power Company

Dow is one of the largest users of process heat in the United States. In 1967, it contracted with Consumers to purchase heat from a dual-purpose nuclear power plant which Consumers would build near the Dow complex at Midland, Michigan.

Although construction of the Midland Station has been greatly delayed by the construction regulation process, it is interesting to examine the plans for this operation.

The nuclear station will consist of two 855 MW(e) units. The first unit will be equipped as a dual-purpose plant to generate 525 MW(e) for normal operation, while furnishing 3.6 million pounds of steam (at 180 psig) per hour and 0.4 million pounds of 675 psig steam per hour. The second unit is to be normally operated to produce 855 MW(e) of power but is equipped to replace the first unit as a steam producer when the first unit is shut down. The second unit is thus a standby unit (with respect to steam). Dow plans to hold its present fossil-fueled boilers on a standby basis to back up the nuclear units.

Complete or ideal dual-purpose operation of power plants, wherein all the waste heat is used, is not possible; however, the Midland example shows that substantial savings can still be realized in the future steam/power costs (see Table 5).

At the present time (October 1973), a construction permit has finally been issued but during the four years of litigation, costs have risen from

Table 5. Dow Savings with Midland (Consumers Power Company).

	Existing Dow Power Facilities		New Dow Facilities	
	Coal 1972	Oil 1980	Oil 1980	Nuclear 1980
Process Steam ($/1000 lb)	0.71	1.15	1.6	0.62
Electricity (¢/kWhr)	1.08	1.5	2.1	1.08

Source: Table taken from "What AEC's First Two Final Environmental Statements Look Like," Nuclear Industries, April 1971, p. 18.

from $349 million to an estimated $770 million, and the operational date extended from 1975 to 1979–1980.[26]

Water Desalting Plants

Salt water distillation plants are the most widespread users of steam from dual-purpose power stations. There are presently at least 51 such desalination plants with capacities greater than a million gallons per day (MGD) and a combined output of 170 MGD. Typical dual-purpose distillation plants are operating in Hong Kong, Kuwait, the Virgin Islands, Saudia Arabia, Nassau, Bahamas, and Tijuana, Mexico. Water production varies from 2.5 MGD to 48 MGD and electrical output from 25 Mw to 250 Mw.

The Tijuana Plant

The Tijuana Plant [7.5 MGD and 75 MW(e)] is representative of most of these in that steam at 245°F, 27 psia, is fed to two multistage flash evaporators which produce 10 pounds of water per pound of steam.

The station produces prime steam at 900 psia and the electrical generating cycle efficiency is about 31% when operated for power only. The oil requirement is about 36,000 lb/hr. A water only plant of 7.5 MGD capacity would consume 15,500 pounds of oil per hour, making the total oil consumption for the two: 51,500 lb/hr. The dual-purpose plant requires only 44,000 lb oil/hr, so the net savings in oil use is about 7,500 lb/hr, or a 15% reduction.

Russian's BN-350 Reactor Station

One of the world's largest desalting plants is attached to the world's largest breeder reactor – Russia's BN-350 sodium-cooled reactor at Shevchenko. This station has been producing water for several years from a separate boiler but the reactor became critical only a year ago. Although we have no progress report since last November, the goal of this 1000 MW(t) dual-purpose plant is to produce 150 MW(e) and 32 million gallons per day of fresh water from the Caspian Sea.

SUMMARY REMARKS

The use of heat now being rejected in warm effluents has been successfully demonstrated in several small installations in this country. It appears that the most fruitful and immediate uses of such heat will be in agricultural and aquacultural applications.

As energy costs and food prices rise, the attractiveness of intensive food production systems using zero or very low cost heat will increase. A few large demonstrations of the economic feasibility of closed-environment agriculture warmed by rejected heat are needed before more widespread use of waste heat for agriculture occurs. One such demonstration is planned by the TVA, but additional efforts in different climates and economic and marketing conditions must be initiated before large-scale expansion occurs.

The use of waste heat in aquaculture is beginning to attract significant commercial attention. The success of the Long Island Oyster Farms, the efforts of Aquamarine Farms, the Florida Crystal River Project, and others are all evidence of this. With the diminishing source of natural supply of fish and seafood, commercial applications of thermal aquaculture seem likely to increase.

The operating history of plants such as the Linden generating station in New Jersey, the Baton Rouge Power Plant in Louisiana, and many desalination plants have demonstrated that dual-purpose power plants can effectively improve system efficiency and fuel economy. Steam used by industry in 1972 amounted to 12×10^{15} Btu, or about 16.5% of the total U. S. energy budget. Some of this demand could be satisfied by having industrial users of steam adjacent to steam power plants. Each such combined operation will save 15 to 20% of the fuel required for separate individual operations in addition to equivalent reduction in thermal and atmospheric pollution.

Only limited applications of dual-purpose central station plants have been made, although significant savings in fuel and improvements in overall efficiency are possible. So far industry has not had a strong incentive to seek process heat from utilities and most utilities have not taken the initiative to sell steam. A catalyst to bring together the steam supplier and steam user is needed. Energy costs as they continue to increase may prove to be that catalyst.

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