The Federal Role in Dry and Wet/Dry Cooling Tower
Research, Development and Demonstration

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ABSTRACT

This study concludes that it is appropriate for the Energy Research and Development Administration (or its successor) to sponsor a program of fiscal, technical and management support directed at providing a commercial advanced concept wet/dry (or dry) cooling technology for electric utility use within ten years.

This federal role is thought to be appropriate for several reasons, including:

- The need for such technology, although expected to grow only slowly at first, will eventually be quite widespread.
- Wet/dry and dry cooling tower technology is currently available, but successful development of an advanced concept should produce significant cost savings for this component of power plant costs.
- Established cooling tower vendors do not appear to have sufficient research dollars available to support a program of the magnitude planned by ERDA, although at least one non-vendor advanced concept development project is underway.
- The Electric Power Research Institute (EPRI), the State of California and potentially other entities have expressed a willingness to support the ERDA program with significant funds, but state that they cannot assume complete funding at this time.

-Even without the shared funding mentioned above, the ERDA program is expected to produce discounted public and/or private industry benefits in excess of its costs.

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1. Introduction

The bulk of base- and intermediate-load electricity will continue to be generated using a steam Rankine cycle, irrespective of fuel type. Large amounts of low grade thermal energy removed from steam condensers for this process will therefore need to be dissipated to the environment (or used beneficially). The most economical and widely used technique for disposal of this 'waste' heat is by once-through cooling of the condenser (whereby a large volume of fresh or saline water is passed directly through the condenser tubes and then returned to the water source). Yet a variety of environmental and regulatory constraints suggest that a significant proportion of future steam plant installations will employ alternative 'closed-cycle' methods of condenser cooling, such as wet cooling towers, cooling ponds or canals, dry cooling towers, or some combination of these technologies. Each of these alternatives will exact certain cost, performance or environmental impact penalties relative to once-through cooling, but they also uniformly eliminate thermal pollution of major water resources by electric power stations, an important constraint to the predicted rapid growth of electric power supply.

In anticipation of potential widespread demand for alternative closed-cycle cooling methods, the Dry Cooling Tower Project of the federal Energy Research and Development Administration (ERDA) is continuing research initiated by the former Atomic Energy Commission to develop cost effective dry and wet/dry cooling tower (DW/DCT) systems for utility use. These systems increase the siting

flexibility for new power stations where water is expensive or unavailable and can be made to have negligible environmental impact.

This ERDA research program has three major components:

1) Limited involvement in demonstration and testing of present day dry and wet/dry cooling technologies, 2) research aimed at improving the physical and cost performance of present- and near-term technology, and 3) development, construction and testing of an optimized, advanced concept for dry or wet/dry cooling.

The limited support associated with the present-day technology demonstration program is being carried out jointly with EPRI at a power plant owned by Southern California Edison, with a combined wet/dry tower supplied by Ecodyne.

The technology improvement portion of the ERDA program is funding several projects, including new concept analysis performed by M.I.T., the prediction of wind and inversion effects on natural draft tower performance (and methods of mitigating adverse impacts) performed at Cornell University, and innovative heat transfer surface production and testing performed by the Curtiss-Wright Company.

The advanced concept Dry Cooling Tower Development Program, which receives the largest percentage of funding of the overall program, was initiated at Battelle Pacific Northwest Laboratories (BNWL) with the following objectives:

- To develop economic and performance models for cost optimization of complete heat rejection systems using dry (or wet/dry) cooling.
- Analysis and dissemination of performance and operating data derived from utility experience with existing dry cooling systems (both domestic and foreign) as a basis for

advanced concept work.

- Demonstration of advanced cooling tower concepts to increase the confidence of utilities in the employment of such systems.

The ultimate objective of this ERDA program is: to develop marketable advanced cooling tower technology to enable electric utilities to utilize reasonable cost dry or wet/dry cooling for thermal power plants whenever economic, ecological, and/or regulatory conditions favor this adoption.

Much of the ERDA program work associated with the demonstration and design improvements of present-day technology is nearing completion. The longer-term, advanced concepts development program at BNWL has progressed through the stages of modeling, performance analysis and cost assessment, and is preparing (upon funding approval) to construct and test a 10 MWt demonstration application of the program's preferred wet/dry concept, an indirect ammonia-loop system using air-side deluge with water to meet critical, design-day thermal load conditions. This demonstration project is planned as a cooperative effort with significant industrial (Electric Power Research Institute) and state government (State of California) support.

Donovan, Hamester and Rattien, Inc. (DHR) has conducted a study to assess the government's role in this research, development and demonstration (RD&D) effort, and based upon independent analysis and contacts with those interested in DW/DCT technology development, to help define an appropriate federal role given the current and expected future demand for this technology.

The DHR effort centers on four characteristics of ERDA's relationship to DW/DCT technology development:

- 1) The current status of DW/DCT technology RD&D and system implementation.
- 2) The economic barriers to DW/DCT RD&D as expressed by the following entities: vendors, utilities, pertinent federal divisions and private firms with new ideas.
- 3) Utility and vendor attitudes towards federal support for DW/DCT RD&D; specifically how such support would be useful to the utilities and how new technology might interface with vendor's product lines.
- 4) Governmental agencies positions relative to federal support of DW/DCT RD&D, including federal regulatory agencies, fiscal agencies and R&D related groups, and their state or regional counterparts where appropriate.

The DHR Study has considered these points in detail and developed recommendations for federal support of cooling tower RD&D, considering specifically the types of technical support, the level of fiscal support, the appropriate recipients for such support, and a suggested timetable over which support might be given.

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2. Summary and Recommendations

Currently available wet/dry cooling technology can be expensive to install and operate and is subject to certain operational problems, such as freezing during cold weather. Nevertheless, it is apparent that a limited number of new steam electric power stations (10-45 GWE, total)⁽¹⁾ will employ wet/dry cooling technologies through the year 2000, although economic factors favor once-through cooling or wet cooling towers in most areas. It is likely that significant use of wet/dry cooling technology will occur in the post-2000 period. (Due to extreme cost penalties in most cases, the total all-dry capacity will probably remain small).

Private commercial development of improved wet/dry cooling equipment is hindered by the relatively small size and limited number of established cooling tower vendors, and by the fact that the somewhat distant market potential does not support large private RD&D investment. Utilities, in general, do not find the RD&D effort necessary to develop such technology to be of overriding importance at this time. Nevertheless, it is projected that significant cost savings could be realized by both utilities and consumers in certain areas of the country if a lower-cost, high performance wet/dry cooling system could be commercialized.

Thus, in general, this study concludes that the DW/DCT program of ERDA is of significant merit and that continued work in this area (sponsored by ERDA and/or others) would be in the public's best interest. ERDA should have a continuing but varying role in

(1) Hendrickson, 1977.

the following suggested timetable for commercialization of advanced dry and wet/dry cooling concepts:

In addition to completing the present-day technology demonstration and improvement programs, ERDA should finalize the advanced concept analysis and evaluation program (with continuing review of the heat pipe concept), and complete the ammonia/deluge preferred concept demonstration facility design, with continuing external cost specification review. This should be followed by construction, operation and documentation of the 10MWt ammonia/deluge module. It would then be appropriate to explore possibilities for conversion and operation of the proposed Kern demonstration plant site as a test-bed facility for further DW/DCT technology developments. At a later time and based on a successful demonstration of the ammonia/deluge module design, specification and installation of a commercial scale application of this advanced DW/DCT technology should be undertaken.

DHR recommends that it would be appropriate for ERDA to continue with the present funding and management support levels of the present-day technology and advanced concept design work outlined above.

It would be an appropriate Federal role to provide 100% of the required fiscal or technical support for an advanced concept demonstration, given that the RD&D investment could produce a desirable benefit/cost ratio. Studies published by BNWL have indicated that such a ratio exists with only a limited application of the technology. Therefore, since significant funding assistance is being offered to ERDA by EPRI and the State of California (and possibly from other sources such as WEST, Western Energy Supply and Transmission Associates) for this demonstration, it would be very difficult

to argue against ERDA support of this project, unless it could be argued with confidence that such a demonstration (and subsequent commercialization) would occur in the near term in the absence of continued federal participation. Such confidence, however, is not warranted at this time. The present willingness of EPRI and the State of California to share the cost of the proposed Kern demonstration facility suggests that technology improvement might come about at some future time without a large ERDA commitment, but it is clear that near-term ERDA participation will assure that the project will be undertaken soon.

Complete funding of the test-bed facility would also be an appropriate Federal role, given that a significant number of alternative concepts could be identified and information dissemination problems relative to proprietary technology could be resolved. Cost-sharing opportunities should be considered, however.

The commercial scale installation should not need to be supported at a high percentage level by the federal government. DW/DCT technology probably does not possess the characteristics which would imply a need for complete federal funding through the commercialization stage; that is, a non-modular, environmentally risky, extremely expensive technology. Although some cost sharing may be appropriate, it is probable that a suitable commercial scale test site and major project support could be provided by the potential users of this technology, including many state and/or federal regulatory and research agencies. Although continuing technical support by ERDA could prove useful at that time, large financial commitments may be unnecessary. It is important that workable relationships with vendors be established before the initiation of commercialization to ensure a smooth transition to commercial technology;

although ERDA may offer some assistance in this regard, such relationships may be properly developed through EPRI or specific utilities.

3. Status of Dry and Wet/Dry Cooling Tower

Technology Development and System Implementation

3.1 Cooling System Requirements and Technology

The steam Rankine cycle commonly used in electric power plants ranges in fuel-to-electricity efficiency from about 25% in old plants to about 45% in the latest designs. Thus a quantity of 'waste' energy between 1.5 and 3 times as great as the electrical output of the plant is produced during normal operations. This energy is released as relatively low-grade thermal energy when the cycle steam, having given up a great part of its kinetic and pressure energy to the electrical turbine, is condensed back to boiler feed-water in the condenser. In most plants, this reject heat is constantly removed from the condenser by a flow of cooling water through the condenser. However, in some designs the thermal energy may be directly dissipated to ambient air without an intermediate fluid.

The broad range of cooling options discussed below stem from consideration of alternative means of producing suitable water (or air) flow to the condenser.

The most common, efficient and low cost form of heat removal from condensers involves a once-through flow of water (in large quantities) from a nearby fresh or saline water-course. Because the temperature of most waterbodies is usually low in relation to steam condensing temperatures, and because water is an efficient heat transfer fluid, condensers for this type of system can be of moderate size with relatively low overall pumping requirements. This is an open-cycle system (as is a direct-to-air condensing system) since the heated cooling fluid is discharged immediately.

Closed-cycle cooling systems employ a fixed volume of fluid which is cycled between the condenser, where it picks up thermal energy, and some reservoir or device where it transfers this energy to air (in most cases a small amount of fresh make-up fluid is added to this volume periodically to avoid corrosion problems). The dissipation side of the closed cycle system may range from water cooling ponds or canals (where the heat is given up by natural processes to the air), to mechanical draft wet or dry towers (where fans induce large amounts of air to come into contact with either the cooling water itself, a wet system, or the exterior of a heat exchanger, a dry system), to natural draft wet or dry towers (where the bouyant, warmed air inside the tower draws cooler air through heat exchangers around the tower base). Note that combinations of wet and dry towers can be made; these systems can produce certain system advantages.

There are drawbacks and penalties associated with each option, some of which limit their usefulness in many situations. Once-through cooling is restricted when the discharge of large quantities of thermal energy to water bodies threatens to adversely affect its ecological balance. Cooling ponds or canals require large amounts of suitable land which may be difficult or expensive to obtain. Wet cooling towers of both types are significantly more expensive than once-through cooling, and large amounts of water are released to the air as the warm water evaporates. Wet towers typically consume more water than any of the other cooling options.

Dry towers, on the other hand, consume no water other than that necessary to maintain circulating water quality. Air passes

over the heat exchange surface (which may be quite varied in configuration) and absorbs thermal energy from the warmed metal (or plastic in some experimental systems). Because this process is less efficient than evaporative heat transfer, all-dry cooling towers require much larger surface areas and greater air flow rates than wet towers of equal thermal dissipation capacity. All-dry cooling towers are, therefore, much more expensive than their wet counterparts, both in original and in operating costs (if water is very expensive the operating costs of wet systems can be significant).

An interesting compromise is provided in water-short or high water cost areas by combining wet and dry towers. These can be separate wet and dry towers standing side by side, a wet tower with some dry surfaces incorporated, or a typical dry tower with provisions for wetting (or deluging) the air-side surface to make use of the beneficial heat transfer effects of water evaporation. Such wet/dry systems can be operated to use only a small proportion of the water that an all-wet system would require, since the system is operated in a wet fashion only when high ambient temperatures reduce the power dissipation capability of the dry tower.

3.2 Domestic System Implementations and Future Installations

There are perhaps thousands of Dry Cooling Tower and Wet/Dry Cooling Tower installations around the world in 1977. However, only a small fraction of these installations are used for cooling electric power stations, and only a few of these are stations above 100 MWe in size.

There are a significant number of DCT installations in Europe. Some of these installations are at power plants of 50-160 MWe in size, and their operating experience should prove valuable to American utilities. Dry cooling experience in Europe has been usefully documented by the Battelle Pacific Northwest Laboratory (European Dry Cooling Tower Operating Experience, BNWL-1995, DeSteele and Simhan, March, 1976).

In the United States there are but two all-dry cooled electric power units in current operation. These are the Neil Simpson Station 20 MWe Unit 5 and an associated house turbine of 3 MWe, located near Gillette, Wyoming. The air-cooled condensers associated with these units are direct condensing, and use fans to move ambient air over the air-side heat exchange surface. The larger unit uses a GEA European design direct condensing system. Operation of both these units has been quite satisfactory, the smaller unit having been in operation since 1962, and the larger one since 1969.

In fact, the owner of these two plants - Black Hills Power and Light, has been so favorably impressed that they are installing GEA dry-cooling for their new 330 MWe Wyodak plant. This plant will be the world's largest air-cooled plant when it begins operation in 1978, and should provide invaluable operating and scale-up experience for American utilities in dry-cooling systems.

There is another dry-cooling (with deluge) installation under investigation at the Wyodak plant; this is a private industry venture to demonstrate the feasibility of a heat-pipe concept for dry cooling thermal power stations. This installation is scheduled for initial operation in the fall of 1977 by its two developers, the Foster Wheeler Energy Company and McDonnell-Douglas Corporation.

Like the ERDA/EPRI advanced dry or wet/dry system, this concept uses ammonia as an intermediate heat transfer medium, and is expected to have certain operational advantages over systems using water/steam fluids.* This is a promising development and is being followed with interest by the ERDA program.

CE Lummus Corporation reports that it has installed a dry-cooled condenser system for three 12 MWe power supply units at the Alyeska Pipeline Valdez terminal in Alaska. These units were designed for operation in extreme low temperatures and severe seismic conditions. Full power operation of these units occurred with the first oil flow during the Summer of 1977.

The federal Environmental Protection Agency (EPA) is planning to monitor the performance of an all dry cooled 85 MWe combined cycle power plant under construction in Massachusetts by the Braintree Electric Light Company. R.W. Beck is the architect-engineer firm for this venture; an all-dry cooling system was selected for this plant in part due to the high cost of water at the site.

Two other near term domestic installations will use a variation of all-dry cooling, the wet/dry cooling tower system. The 466 MWe San Juan III Unit under construction by Public Service of New Mexico and Tucson Gas and Electric (scheduled for operation 1979-1981) will use a system of separate dry and wet towers to provide peak-shaved dry cooling, consuming only 40% of normal evaporative cooling water requirements. These towers, supplied by the Marley Company, will constitute the first large scale system demonstrating this concept and will provide valuable experience for all water-short utilities considering such a system.

* For example, the large number of individual heat pipes in such a system would provide redundancy and might facilitate repair procedures.

Another demonstration effort, sponsored with limited support by ERDA and EPRI, will use a hybrid wet/dry tower system supplied by Ecodyne at a 15 MWe unit owned by Southern California Edison. Dry and wet cooling surfaces contained in a complete tower are employed in this concept; some water conservation is achieved, but plume abatement was the major goal in the design of this system.

The primary focus of the ERDA effort in cooling tower technology development centers on demonstration of a water deluged, ammonia loop wet/dry cooling tower module. This module is planned for the Kern plant of the Pacific Gas and Electric Company at Bakersfield, California. This system will reject the waste heat from a 6 MWe house turbine, and will employ some form of ammonia loop heat transfer with water deluge of air-side surfaces during hot weather. This installation will serve to validate these technical concepts for domestic utility use, and will explore the cost-reduction potential for DW/DCT of the ammonia and deluge concepts. This demonstration module would be the first step towards a commercial-size demonstration at a plant of 200 MWe or larger. In addition, the approximately 10 MWt module could be converted at some future time to a general use facility for the testing of dry or wet/dry cooling tower components.

3.3 Status of Dry and Wet/Dry Cooling Tower Research, Development and Demonstration

The previous sections show that, although dry cooling (or wet/dry systems) are not in general use, there is activity in the field by the federal government, utilities and vendors, and within several years 5 or 6 DW/DCT installations will be producing significant

amounts of operating data and cost definition information. These activities and demonstration projects represent the primary focus of research in this field, for the following reasons: The science of heat transfer is quite advanced, and although some fundamental concepts in convective and phase change theory need elucidation, most basic performance parameters are well known and quantifiable. The bulk of heat transfer research efforts center, therefore, on system designs, optimization, and cost-reduction. Dry and wet/dry systems, in particular, are considered to be too expensive for general use at this time, and the electric power industry feels that reductions in the capital and operating costs of such technology will be required before its use would become widespread.

System design and optimization work are comparatively low budget research items which are underway at many commercial and educational institutions around the country. Geothermal power, ocean thermal power, solar thermal electric power, refrigeration and cooling systems and bottoming power cycle research are all somewhat related, for instance, to heat transfer concepts utilized in designing an ammonia loop DW/DCT.

It may be expected, therefore, to find a number of DW/DCT designs both technically feasible and promising. Many of these designs, however, may not produce the significant cost savings desired. The status of Dry and Wet/Dry Cooling Tower RD&D centers, therefore, on development and demonstration of cost-effective approaches; proof-of-concept systems and pilot plant demonstrations are needed most. Unfortunately, these are the costly aspects of RD&D and can only be undertaken after a careful concept evaluation process.

At present, only the federal government seems prepared or capable to fund a demonstration of an improved concept of wet/dry

cooling of significant scale. The Foster-Wheeler heat pipe effort, for example, would probably require one more scale-up demonstration before it could be tested at a modular size appropriate for commercial use.

Thus evaluation of the status of DW/DCT RD&D turns on the question of whether or not funds are available to support large scale demonstrations of improved concepts. Demonstrations at pre-commercial scale will be required before the market for advanced cooling technology can develop fully. Yet although such demonstrations are costly, only one or two successful concepts are required; if all of the research plans described above can be completed it is likely that this goal of commercial advanced technology will be achieved.

4. The Need for Dry and Wet/Dry Cooling

4.1 Preference for Cooling System Options

In lieu of future environmental impact or water consumption regulations, there is a hierarchy of preference for presently available cooling system options based on costs. This hierarchy, however, is subject to region-by-region variations based on thermal discharge regulations, local climatological conditions, land costs and local decisions on aesthetic considerations. In general, however, it is expected that utilities would select cooling options in the following cost-related order; once-through cooling (fresh or saline as applicable); cooling ponds or canals where large areas are available; spray ponds or canals; wet (evaporative) cooling towers of mechanical or natural draft design.

It is recognized that the completely dry tower is necessary in very few situations. It has been shown by the ERDA program that if as little as 1% of the water required by an all-wet tower is available, the size of a wet/dry tower could be 32% smaller than an all-dry tower (by using a deluge technique).

It is also interesting to note that the least expensive options are burdened with significant thermal discharge or land use impacts, while wet towers consume prodigious amounts of water and can, under certain circumstances, create adverse local weather conditions. As the overall installed electrical capacity grows, however, available sites for once-through, pond, canal and wet tower cooling (the last due to consumptive use of water) are expected to diminish in number, thus creating a demand for the environmentally benign wet/dry, and in certain locations, dry cooling technologies. The critical question is, of course, when and at what rate will this demand materialize?

In this light the goal of the advanced concept development effort is clear - to assure that when DW/DCT demand begins to be felt, there are commercially available advanced wet/dry cooling technologies which will be less costly than the technology which would have otherwise been utilized.

4.2 Factors Encouraging the Use of DW/DCT

Although perhaps not of overriding importance today, there are several factors which, in the long-term, will promote the increased use of wet/dry (and in a few extreme cases, all-dry) cooling technology. The major (and somewhat related) influences stem from considerations of water scarcity, water cost, siting flexibility and governmental regulations (which might reflect societal choices to use available water for other purposes than power plant cooling; several states have established priorities for water use which do not favor consumptive use by utilities).

Water scarcity or unavailability is a definitive influence which can force the use of water conserving cooling options. When there is no other choice than to employ a minimum water-use system, regardless of cost, then wet/dry (or even all-dry) towers are justified. Absolute water scarcity is quite regional in nature, and is presently confined to areas west of the Mississippi River. However, some Eastern regions such as the Delaware Valley, the Susquehanna Valley and Florida are nearing water use limits.

Water scarcity is an extreme case of another factor encouraging the use of wet/dry or dry cooling systems; this factor is relative water cost (in a shortage situation water may be considered unavailable at 'reasonable' cost). Recent studies by General Electric (1976), United Engineers and Constructors (1976), and the Iowa Institute of Hydraulic Research (1976), indicate that the cost of

water for use in wet cooling towers would need to approach \$1.60-\$2.50 per 1,000 gallons before a switch (in the planning sense) to a conventional combined wet/dry tower system would be indicated for utility use. The industrial cost of water in most areas is currently much less than these figures, and interestingly, large volumes of 'waste' water can be treated for reuse as cooling water for costs usually less than these.

It is important to note that in many states water rights for existing uses (mainly agricultural) can be transferred or purchased at costs less than these costs. This is due, in part, to the fact that the Federal and State governments have intentionally priced agricultural water at the costs of pumping and distribution to encourage agricultural uses.

If the wet/dry technology cost reduction goal of the ERDA advanced concept program can be achieved, then, of course, the change-over water cost is lowered. The effect of such cost reductions have not yet been evaluated in this context.

Thus where water is available it can in most cases be treated and delivered to power plants at costs which indicate wet, evaporative cooling as the optimum choice (when once-through cooling or ponds are not practical).

In this regard it would be useful to know how water, as a sometimes scarce commodity in high demand, may rise in price over time. In the long-term, water costs might rise enough to justify wet/dry cooling in much of the nation on this basis alone, irrespective of environmental or siting flexibility benefits, but this is not an imminent prospect.

Siting flexibility is, of course, a major advantage associated with the use of wet/dry or dry towers. All steam electric plants require a certain amount of water for boiler make-up and domestic use. These are relatively small requirements, however, when compared to the consumptive use of water by wet cooling towers, and such small uses can be supplied by water available at the plant or water trucked to the site. Since wet/dry towers can be designed and operated with 40%, 20% or even 5% of the water needs of wet towers, the number of usable sites for power plants would be expanded significantly (since some water is usually available in most areas).

This benefit extends both to new plants located in water-short areas and to those which can be co-located with existing power stations, in order to make use of established transmission corridors and exclusion areas when extra water is not available. By using wet/dry cooling technology and sharing available water it should be possible to greatly expand generating capacity at an existing site without a significant rise in consumptive water requirements. If existing plants could be retrofitted with wet/dry towers (replacing wet towers) overall water requirements at an expanded site could even be reduced.

At some point, of course, all of these factors may be considered in the development and promulgation of regulations which may either specify or implicitly require the use of wet/dry cooling equipment. These regulations could be issued on either a national or state-by-state (more likely) basis, and would be designed to produce certain social benefits which the utility's limited economic comparison of alternatives might not consider (such as the state-wide or regional impact of displaced agricultural production if water rights were purchased).

4.3 Regional Considerations

In considering these factors it is important to keep the great regional differences in electric power needs and water availability in mind. For example, although both the Northeast and Southeast regions have large absolute amounts of fresh water, the available capacity for new consumptive or thermal discharge use of water in the Northeast may be considerably less than in the Southeast.

On the other hand, there is little or no water available at all in parts of the Southwest, such that use of current wet/dry cooling technology in some instances is already justified.

In other states, such as California, there are significant amounts of water available (on average) but the greater part is either used for agricultural irrigation (agriculture is a major industry for the state), or is not available at likely sites for new electric capacity.

Thus, significant competition for energy-related use of fresh water is likely to first occur in the coal- and oil shale-rich western states, where annual rainfall is relatively low and the irrigation of agricultural land is commonplace. Such competition is also likely in some of the highly developed areas in the East, where industrial, commercial and domestic consumption represents a greater percentage of consumptive demands.

Of course, as the population of the United States continues to grow and re-distribute itself to the most 'desirable' areas of the country, economic competition for scarce resources (whether they be clean water, clean air or even 'quietness') will become more widespread. There is some present evidence that populations are already shifting in response to the energy situation, relative to heating problems. In addition, energy scarcity related trends such

as accelerated electrification may change some present patterns considerably. In the long-term, wet/dry cooling may eventually be the only common form of steam plant cooling.

4.4 The Expected Market for Dry and Wet/Dry Cooling

The developing market for water-conserving cooling technologies is quite unpredictable, due to uncertainties associated with the growth of electricity demand in various regions, the relative development rates of coal and nuclear power, the cost of water in many different basins, the individual requirements of the many state Public Service and Utility Commissions, and the possibility of future state and/or federal regulations which may dictate water use patterns for utilities outright or indirectly require the use of wet/dry cooling systems.

It is also not clear what the demand for advanced cooling tower technologies might be in Europe, where significant numbers of relatively small dry-cooled stations already exist, or in developing countries which are expanding their electric power sector, such as those in the Mid-East. Thus foreign markets may offer opportunities to domestic vendors in the advanced cooling tower field.

In spite of these uncertainties, some estimates of the domestic market for wet/dry cooling through the year 2000 have been made.

A recent General Electric study (1976) predicted that 6 to 23 gigawatts (electric) (GWe) of wet/dry cooled nuclear power plants would be installed in the Upper and Lower Colorado basins in the period 1985-2000; this implies (assuming reasonable coal plant growth) an overall demand for wet/dry cooled steam plants (both nuclear and coal) over this period of between 11 and 42 GWe. This demand would be entirely located in the Upper and Lower Colorado River Basins.

This study assumed that sufficient water for wet cooling could be obtained from a variety of sources (ocean, reclaimed waste water, ground water) in other dry regions, such as the Texas Gulf and California. If transfers of water rights from agricultural to power plant use were considered feasible (the General Electric study did not make this assumption) the demand estimate would be smaller by an undetermined amount.

A recent study by the Hanford Engineering Development Laboratory (HEDL, 1976) predicted that 22 to 44 GWe of wet/dry cooled power stations would be required west of the Mississippi in the period 1990-2000, with possible additions to these figures from the Mid-Atlantic States. One-half of this demand was found to occur in California (14-22 GWe), while almost all of the rest occurred in the Southern Great Plains (4-11 GWe), the Denver area (2-5 GWe) and the Great Basin (1 GWe). In this HEDL study, only 3-6 GWe of new capacity were predicted to require wet/dry cooling for the period 1990-2000 in the Upper and Lower Colorado Basins, based on the assumption that significant quantities of groundwater would be made available for utility use. Such use would be doubtful, however, if this practice could be shown to cause depletion or salinization of the aquifers. Also, this study assumed that 3/4 of the projected new capacity in California could obtain cooling water from waste water and by transfer of irrigation water rights.

However, if transfers of water rights to utilities were prohibited and if seaside once-through cooling were not permitted at all in California, these HEDL estimates for Wet/Dry cooling would be much higher (as much as 100 GWe total, with 75 GWe in California).

In a recent Battelle program document (Hendrickson, 1977), these water availability studies were analyzed and assessed; in their

view the resulting expected demand for wet/dry cooling over the period 1985-2000 was stated to be approximately 20 GWe, centered primarily in the Southwest.

The variability of these estimates highlights the complicated economic, political and technical relationships involved in predicting the demand for wet/dry cooling tower technology; such estimates will be in a continuing state of flux as these factors change in relative importance.

Nevertheless, it is apparent that there is a fairly well documented case for a cumulative demand of at least 20 GWe of dry or wet/dry cooling through 1995-2000; depending on the variable factors listed above this figure could be considerably higher.

5. The Goals and Roles of Interest Groups Affected by Dry and Wet/Dry Cooling Tower RD&D

Ours is a complex and multi-faceted society. The introduction of new technology involves many different interest groups and can disturb existing relationships.

Having determined the status of existing wet/dry cooling technology and RD&D efforts, and established an expected demand level for this technology, we now turn to a brief analysis of the roles that various interest groups affected by this RD&D effort may take as the ERDA program moves towards demonstration and eventual commercialization of its advanced concept technology.

5.1 The Interest Groups

A complete list of interest groups affected by the ERDA dry and wet/dry cooling tower program would include:

- Federal RD&D Agencies
- Federal Regulatory Agencies
- Federal Fiscal Agencies
- State RD&D Agencies
- State Regulatory Agencies, including Public Utility Commissions
- State Fiscal Agencies
- Utilities
- Utility Research Organizations
- Established Cooling Tower vendors
- Emerging or Potential Cooling Tower vendors
- The General Public
- Special Interest Groups/Environmentalists and Conservationists

The roles of the federal and state agencies are self-evident. Utilities strive to provide adequate quantities of reliable, minimum cost electricity to their customers. Utility research organizations such as EPRI identify and fund research which can make the utilities' tasks easier with our rapidly changing energy and environmental-policy world.

Established cooling tower vendors try to remain viable companies while meeting the market demand for cooling tower installations. Their modest research budgets are usually aimed towards incremental performance and cost-effectiveness improvements in components. New cooling tower vendors are exploring opportunities which represent technology spin-offs from other unrelated research or product development. The general public, as a group, is interested in increasing national wealth and in improving the quality of life, which includes consideration of the natural environment and its preservation. Special interest groups take an active role in the legal and political aspects of such preservation.

5.2 Groups with Common and Adversarial Interests

Identifiable common interests supporting the ERDA DW/DCT program exist among all of the identified groups except the following, which might be expected to take adversarial roles:

- Federal and State Fiscal Agencies
- Utilities in water-rich areas
- Established vendors
- New vendors who feel they already have a competitive product

The missions of the various federal and state fiscal agencies requires them to take a stern dollar-conscious view towards most research projects and their funding levels. They may therefore take the ERDA (or state support of ERDA) project to task with respect

to the identifiable benefits of the program, or in relation to the benefits of other more promising expenditures.

Utilities in water-rich areas may take the position that if the program were to achieve its goals, it would increase the likelihood of regulations which might require them (in their view, unnecessarily) to use wet/dry cooling technologies for new capacity. This would be reminiscent of the problems stemming from the "no once-through cooling" directive of EPA.

Established vendors are now marketing wet/dry cooling technology which will be employed, to a certain extent, over the near term. To the extent that the development of advanced concepts will displace sales of present-day technology, it may be expected that certain vendors will be dissatisfied with the ERDA effort. However, vendors may also take the view that the development of public information derived, lower-cost wet/dry cooling technology will serve to broaden a somewhat narrow market, in that more of these systems will be economical.

Theoretically, if a vendor firm could market a successful advanced wet/dry cooling concept in the near future, its natural position would be to discourage such federal efforts to the extent that an ERDA effort would displace some of its identified market to other manufacturers.

5.3 The Public View

Introduction of new technology has created societal benefits (and usually smaller costs) since the advent of technology-using man; research and development are necessary functions in any modern society which desires to improve its quality of life.

To the extent that the ERDA program can develop commercial wet/dry cooling technology with a lower intrinsic cost, society will realize a net gain in benefits. These may result from lower resource requirements for energy systems, lower electricity costs to consumers, and reduced environmental costs stemming from energy resource conversion.

From this perspective society supports profitable research (based on priorities) whenever sufficient research funds (which in some sense represent the surplus benefits of past advancements in technology) are available. Thus the ERDA program would be considered beneficial and worthy in this regard.

Although certain costs may be incurred by specific interest groups whenever new technology is introduced (such as displaced markets for existing technology), it appears that from a societal viewpoint, such problems 'average out' with time, and in fact, new (and more economical) technology can be considered as an opportunity to existing vendors, and not as a threat.

6. Economic Barriers to New Cooling Technology Development

There are several distinct groups which are involved in DW/DCT RD&D, including utilities, vendors, pertinent governmental (federal or state) divisions, and private non-vendor firms with "new" ideas. Each of these may have specific limitations or requirements in terms of funds available for such research.

6.1 Utilities

With few exceptions electric utilities do very little technical RD&D individually (although groups such as the Electric Power Research Institute (EPRI) perform such work for the utilities collectively).

The traditional route of technical progress has been via the bid responses of boiler, turbine, generator, condenser and transmission and distribution equipment vendors. The reason for this pattern is that the utility role has been narrowly defined to be the service of electric power customers, rather than technology development as such. This is in part the result of state regulatory commissions having narrowly defined the basis upon which utility rates are calculated. In general, only expenses associated with plants actually in service (and occasionally, plants under construction) are allowable in the "rate base" upon which the utility's return on investment is calculated. Expenses due to generic RD&D not associated with a particular plant are usually excluded from the rate base, reducing utility's permissible earnings. Only by contribution to EPRI can most utilities fund generic RD&D and be permitted a return on their investment; this is a major reason for the widespread support which EPRI enjoys, and the increasing volume of RD&D which it directs (\$150 million for 1977).

Except for EPRI activity, which will be discussed separately, utility RD&D is therefore necessarily related to the design and construction of individual plants and their subsystems. With regard to DW/DCT, this restricts utility RD&D activity to those few companies whose current or near-term water availability problems are so severe that the otherwise prohibitive costs of dry or wet/dry cooling become potentially acceptable. Specifications for candidate systems and equipment are then developed, and vendors are invited to bid their best available technology. Unfortunately (from an RD&D viewpoint), the volume of business generated by current utility needs of that type is very small; Wyodak and San Juan III and IV are the only present examples of significant size. The rate of technical progress under such conditions is slow, as only a few vendors can participate, although success at these plants could rapidly lead to other installations of such equipment.

One might expect that since water availability problems will become more severe with time as total installed generating capacity increases, the market for DW/DCT would also increase. However, electric demand growth in truly arid areas over the next ten years or so may not be large enough to strain existing vendor capacity, and most utilities elsewhere foresee no significant need for DW/DCT until late in the 1990's or beyond 2000. This is well beyond the technical (as contrasted with demand) planning horizon of most utilities; plant-specific R&D for turn-of-the-century facilities will not get underway until the late 1980's. Thus one cannot expect much utility activity in DW/DCT RD&D until that time with the limited and incremental advances on such a timetable.

EPRI activity is another matter. EPRI is now apparently prepared to spend a significant fraction of its heat rejection research budget on DW/DCT technology demonstration in a joint program with ERDA; this reflects EPRI concern that the need for alternative approaches may grow faster in the future than the ability of vendors to provide them. Most work supported by EPRI is short or mid-term and is of widespread if not national interest among member utilities. Thus the decision by EPRI to participate significantly in DW/DCT RD&D implies that, while not an immediate nationwide problem, water for condenser cooling will eventually become so scarce as to justify an early and diligent search for effective alternatives. Indeed, such a search must soon be underway to provide commercial size technology which utilities could specify with confidence for 1990's requirements.

6.2 Vendors

The ability of cooling equipment vendors to conduct RD&D on alternative DW/DCT concepts is severely limited by the size of their research budgets and by the relatively distant (in time) demand for such technologies. The domestic vendor community includes only five or six firms; most have total annual sales of less than \$200 million and operate on net profit margins of 2-3%. Only Marley derives most of its income from cooling equipment (about 85%) and has enough net earnings (about \$15 million on sales of \$200 million+ in 1976) to conduct a substantial in-house RD&D effort. Although data for Hudson Products were not available the remaining domestic firms (Research-Cottrell and Ecodyne) apparently do not derive sufficient income from cooling-equipment sales to support a significant research effort.

The lack of data for Hudson is unfortunate; as a wholly-owned subsidiary of J. Ray McDermott & Co., specialists in offshore oil construction with annual sales over \$1 billion and an operating profit margin of about 20%, Hudson has access to substantial venture funding which could, if successfully applied, catapult it into a position of industry leadership. However, it is likely that the yield on venture capital is greater in the offshore oil industry than in the cooling tower business.

The preliminary ERDA program benefit/cost analysis suggests an internal, before-tax rate of return of 14.5%, with the benefits accruing to the public and to vendors as a group. Industrial or commercial business ventures often require at least 18% return (after taxes) with full benefits capture by the firm. Thus a very legitimate government venture may be quite deficient on a commercial basis. Therefore, in the case of Hudson the availability of such funding is questionable. Nonetheless, the recently successful bid of J. Ray McDermott for control of Babcock and Wilcox, a major boiler builder, suggests an interest by McDermott in energy related activities other than petroleum exploration. Whether that interest extends to DW/DCT is an interesting and potentially significant question.

On the whole, however, it appears unlikely that more than a few million dollars a year is spent by the entire cooling equipment industry on RD&D, and equally unlikely that more than a few hundred thousand dollars are expended annually on dry or wet/dry technology development relevant to utility needs. Given the present and expected near-term softness of the utility market for

DW/DCT that is not an appropriate level of private sector activity. Only if the market were to receive a sharp stimulus, such as a prohibition of the consumptive use of surface water for condenser cooling by the State of California or several smaller states, would one expect the vendor industry to increase its RD&D activity. The present market volume simply will not support the financial risk to vendors of research programs targeted on the long-term projections involved.

6.3 Private Firms with New Ideas

"New Idea" firms, not presently in the cooling equipment market, constitute the only volatile source of DW/DCT RD&D support. The current McDonnell-Douglas/Foster-Wheeler project at Wyodak is an example of a serious foray into the field by an "outsider". McDonnell-Douglas is a high-technology 'defense' firm for whom the utility market offers potentially significant sales volume for one of its commercial technology spinoffs (heat pipes). Foster-Wheeler provides expertise in dealing with the utility industry, using its reputation as a builder of steam and petrochemical plants. Their combined profit margins are about the same as that of the cooling vendors, but their sales volume worldwide is sufficient to support multi-million-dollar RD&D ventures. Such firms and combinations can propose radical rather than evolutionary changes in technology and back their proposals with sufficiently attractive risk-sharing to gain entry into the utility market, particularly if the technology proposed is commercial in other markets (as is the heat pipe in certain special applications).

6.4 Federal Limitations

In principle there is no real limitation to the research funds which could be applied to a specific, crucial national research need. In fact, of course, there are myriad conflicting goals and priorities which must be respected when considering effective limits for federal support of research.

Energy supply and conservation and environmental protection are current national objectives of significance. Thus research monies for DW/DCT programs can be considered to be in the national interest. The perspective shifts on limitations, therefore, to consideration of the priority of this effort in relation to other programs of national need. This is a broad question which relates directly to the formulation of specific national energy policies, some of which may change with time to reflect the world situation. Thus it is not possible to precisely define a federal limitation for DW/DCT RD&D, other than to state that this program must compete on its merits with other programs of national importance.

The benefit/cost analysis of the DW/DCT program performed by BNWL is typical of techniques used to evaluate such alternatives; the 14.5% internal rate of return projected with BNWL's assumptions is considered to be moderately favorable by governmental fiscal agencies.

6.5 Private Economic Limitations as Related to Federal Activity

It is important to briefly consider the possibility that federal research activity in certain areas may encourage others with similar intentions to shift their research dollars to different projects, rather than to duplicate a role which the government has already assumed. This is a possibility with private vendor

firms which would then not be able to exclusively capture benefits stemming from such RD&D.

However, this situation is reversed with respect to other governmental entities (such as states) or organizations which may be communal beneficiaries of such research. Consider that the State of California and EPRI have an interest in developing commercial DW/DCT technology and have a certain amount of research funds which are presently insufficient to independently achieve this goal. By joining with a federal effort, they can receive the benefits of new technology with a reduced research investment.

7. Utility and Vendor Attitudes Towards Various Federal Roles in Dry and Wet/Dry Cooling Tower Research, Development and Demonstration

7.1 Utilities' Views

Utilities are caught squarely in the midst of the problem of how to introduce effective new technology into commercial service. While ERDA would like to see promising, cost-reducing alternatives realized at commercial scale, the Federal Power Commission evaluates the quality of utility service chiefly on the basis of reliability and adequacy of reserve capacity. These considerations are also important to the regulatory agencies, such as the Environmental Protection Agency and the State Public Utility Commissions. Since the introduction of any new technology at large scale involves the installation of less-well-proven equipment, service reliability usually decreases until operating performance of the new equipment is satisfactorily established. Utilities are unavoidably at risk as innovators, and their reward structure inhibits innovation; the establishment of the Department of Energy could affect the situation in a helpful way if the separate interests of ERDA, the Federal Power Commission and the Federal Energy Administration can be merged, and a unified policy developed for the benefit of utility management.

Meanwhile, a problem exists for an increasing number of electric utilities who currently or in the near future find insufficient water available to provide cooling for new capacity using once-through or wet cooling. Dry cooling is prohibitively expensive in all but the most arid regions, whereas a combination wet/dry cooling scheme

is relatively less costly. However, conventional wet/dry cooling systems are burdened with substantial idle wet tower capacity under most operating conditions which drives their cost strongly above current wet systems.

Using information developed by BNWL outlining the interest of individual utilities in wet/dry and dry cooling technology, utilities were surveyed to determine their current efforts and plans with regard to dry or wet/dry cooling systems, and to solicit their opinions concerning the need for and appropriateness of ERDA activity in DW/DCT RD&D in general, and that of the proposed ammonia/deluge demonstration in particular.

Other than the well known activities at Wyodak, the Ecodyne unit at Southern California Edison, and the wet/dry Marley hybrid towers included with the San Juan III and IV units of Public Service of New Mexico/Tucson Gas and Electric, none of the utilities contacted had either ongoing efforts in DW/DCT development or specific plans for wet/dry or dry tower installations at currently planned facilities.

Seattle City Light has funded a feasibility evaluation at the University of Washington which suggests that the Pacific Northwest area, with its winter-peaking electrical load, would be an attractive region for introduction of DW/DCT technology. However, the region benefits from an abundance of hydroelectric capacity. Also, much of the electrical demand is near the Pacific coast, where salt-water cooling is a viable alternative to DW/DCT if not limited by environmental constraints.

Many of the utilities on the Eastern Seaboard were planning to use wet towers at near-future installations as necessary if once-through cooling were not permitted for any reason, and others were

including cooling ponds or lakes in their new capacity plans. Nevertheless, there was a strong general opinion that the days of once-through and evaporative cooling are numbered, and that wet/dry or dry cooling would become universal early in the next century.

Faced with the perception that, except for salt water systems, the consumptive use of water for condenser cooling may sooner or later be prohibited, utility planners recognize a nationwide requirement for wet/dry or dry cooling equipment, beginning now in some areas, with grace periods of up to 30 years for utilities in the remainder of the country. They are concerned about the high cost and parasitic power requirements of existing cooling equipment, but recognize their own insistence upon demonstrated reliability at commercial scale as partly responsible for the present lack of alternative hardware. Utility engineering managers are aware of the weakness in today's cooling equipment market, and appreciate the technical and financial risks attending vendor RD&D; consequently, they do not expect much development activity on the part of vendors unless and until market conditions improve substantially.

A variety of opinion was encountered concerning the need for and proper extent of ERDA involvement in DW/DCT RD&D; in general support for early and substantial ERDA efforts was directly related to the perceived severity of local cooling problems. With the exception of a few arid-area representatives who suggested that anything short of a truly massive effort by ERDA would be "too little too late", and one water-rich area individual who believed ERDA/EPRI activities in DW/DCT to be premature, virtually all utility people surveyed considered ERDA support of DW/DCT RD&D to be both timely and appropriate to their current needs or plans. Benefits of ERDA activ-

ity most often cited were evaluation of alternatives not tied to vendor product lines; opportunity for radical as well as evolutionary changes; unbiased evaluation of candidate approaches; and substantially increased potential for timely development of improved DW/DCT equipment. There was also strong support voiced for coordination and cooperation of ERDA and EPRI efforts to maintain utility input to (and influence on) the ERDA program.

Overall, there was general agreement on the need for an ongoing DW/DCT program in advanced concept development to supplement and complement product development efforts by vendors, and recognition of ERDA as the appropriate sponsor. A fair summary of the attitudes of utility representatives toward ERDA activity in DW/DCT RD&D might be that it is a mixture of relief, expectation and apprehension; relief that federal participation will permit the development and unbiased evaluation of new technical approaches at a scale from which utilities may extrapolate without undue risk; expectation that new technologies will in fact be developed to provide condenser cooling with substantial reductions in water consumption, parasitic power and capital cost penalties; and apprehension that the federal program, having assumed primary responsibility for development of advanced concepts may not proceed with sufficient diligence to assure timely availability of new technology to meet anticipated demand. It should be noted that the ability of vendors to supply equipment capable of effective wet/dry or dry cooling was not questioned; the advantage of federal activity in the field was chiefly held to be the increased chance of doing the job at lower utility cost.

Some of the specific comments of utility respondents concerning the ERDA program and the ammonia/deluge demonstration are paraphrased below:

- Demonstration should be done . . . to find the operating problems with new technology and equipment at low risk.
- Demonstration should be a credible test with respect to operating conditions, temperatures, etc., to maximize applicability, establish a reliability record and gain experience in ammonia-handling.
- Some respondents indicated that there is a parallel need for development of high-backpressure turbines*, and for optimization of combined system costs.
- To avoid delays with proprietary difficulties, it is appropriate that non-vendors perform advanced-concept RD&D, as is now occurring.
- Ammonia-based DW/DCT is an attractive alternative to direct condensing schemes above 300 MWe.
- Cooperation with EPRI increases utility confidence in results.
- New heat transfer surfaces offered by non-cooling tower vendors would be accepted by the utility industry if reliability and performance are adequately proven.
- Development efforts should include a study of the environmental benefits versus incremental cost of DW/DCT, to minimize potential for future difficulties such as those experienced by industry and the Environmental Protection Agency with scrubbers. ERDA role is important to meet environmental

* However, there is a consensus among the major turbine makers that the advent of the dry/wet concept alleviates the need for high back-pressure turbines which were thought necessary only a few years ago.

deadlines.

- The non-freezing aspect of the ammonia system is less beneficial in the Southwest where a major portion of the dry/wet market currently exists.
- There is a potential problem with ammonia and deluging in a single demo; effects of the two schemes on performance and reliability must be separated.

7.2 Vendor Attitudes

A generally unfavorable attitude of vendors toward federal support of RD&D in their area would be entirely predictable, given the current market softness, the ability of vendors to furnish wet/dry and dry cooling equipment from existing product lines, and their consequent unwillingness to risk substantial investment at this time in advanced concept research. Successful development of new DW/DCT technology or entry of new firms into the cooling equipment market at any time in the foreseeable future poses economic threats to the vendor community. Assuming a total demand for DW/DCT of 20 GWe by 2000, with annual demand increasing linearly over the period, the 1985 annual demand for these systems would be approximately 1 GWe, roughly equivalent to one or two conventional stations, and well within vendor capacity to supply with currently available technology. Only in the event of a substantial and sustained upturn in market volume could one expect vendors to acquiesce to a high level of non-vendor RD&D support, although the dry/wet market would still be a small portion of the cooling system business. Nevertheless, vendor unease must be viewed as more or less unavoidable.

On the other hand, small vendors may see participation in the federal DW/DCT effort as a means of gaining valuable experience and establishing a marketing position in a new applications area.

In the past, vendors have generally not engaged in large scale, radical departure types of product development, which the ERDA program represents. Vendors have made incremental changes and developments in their product lines, and obtained test results from actual installation of these changes on contracted jobs. This may cause a polarization of attitude regarding participation in the federal program; certain vendors may consider it a chance to develop a new product with minimal RD&D costs while others would reject participation since it would not easily interface with their RD&D 'modus operandi'.

However, certain types of federally supported activity might generate much less opposition than others. For example, development of a test facility for candidate heat transfer surfaces under dry or wet/dry (deluge) conditions, if that facility were made available to all vendors, would arouse little opposition compared to a full-scale commercial demonstration of a new alternative technology. In general, vendor opposition can be expected to increase as any advanced technology approaches commercial scale or offers an apparent near- or mid-term alternative to existing product lines.

Given such vendor reaction, there are several means to minimize it while maintaining an active federal research effort. These include: 1) directing the greater number of efforts (although not necessarily the bulk of funding) toward longer term, advanced concept development and proof-of-concept experiments at moderate scale; 2) limiting federal (but not EPRI) support of nearer-term alternatives to sub-commercial (less than 20 MWe) scale development, with real opportunity for vendor participation in equipment bidding; 3) provision of an appropriate variety of federally-supported facilities for the testing and evaluation of essential system components of both sponsored and vendor origin. The extent of test data publication

could be subject to negotiation, linked to the degree of federal support of the particular testing program.

The above means would recognize the necessity of vendor participation (strongly advocated by the utilities) in the eventual commercialization of new DW/DCT technology, invite their participation in federally supported pre-commercial demonstrations, and provide a continuing opportunity for objective testing and evaluation at low cost of essential equipment items with reasonable preservation of proprietary interests. Further, it would keep vendors abreast of new technology options, a valuable benefit in the event of market surges due to regulatory action by individual states. Since such stimuli, although unpredictable, become increasingly likely with time, continuing involvement of a wide range of vendors and potential vendors in any Federal DW/DCT program is essential if maximum benefit is to be captured by energy consumers.

8. The Need for Federally Supported Dry and Wet/Dry Cooling Tower Research, Development and Demonstration and the Limits of Such Support as Seen by Federal Agencies and Others

8.1 Introduction

There are many federal, state and private organizations which will be involved, by varying degrees, in the development, commercialization and use of Dry or Wet/Dry Cooling Towers (DW/DCT). Some of these organizations will have goals quite compatible with those of ERDA, while others will take an adversarial role. Organizations do not have attitudes and views as such, rather they establish positions and policies related to their mission, which may be regulation, research and development or fiscal review and control.

The following sections, therefore, analyze the roles and positions of various agencies and organizations as they may relate to ERDA's DW/DCT efforts.

8.2 RD&D Related Agencies and Organizations

These groups may be found at the Federal, State and private industry levels. Personnel from several of these groups have been contacted with the following general results:

In general, other federal research groups such as the National Science Foundation or the National Research Council are not sponsoring work directly related to facilitating utility use of dry and wet/dry cooling systems. As such, they would not have any specific position on ERDA's efforts in this area, other than to point out the benefits associated with the availability of a variety of environmental control technologies.

The National Water Resources Council is concerned with the water demand and water pollution aspects of energy development in all areas of the country. They are specifically concerned with the impacts of new technologies such as nuclear, solar or geothermal electricity generation which normally use a smaller working temperature differential and reject more waste heat than their fossil fueled counterparts.

Although the Water Resources Council has no research funds to support the DW/DCT project, they feel that it should go forward at this time due to the thermal discharge and water conservation benefits which it may produce in many fields of energy development.

The Environmental Protection Agency (EPA) has several research-oriented facilities; their Industrial and Environmental Research Laboratory at Research Triangle Park in North Carolina currently conducts research involving the performance and environmental effects of dry cooling towers. The EPA facility has two active projects in dry cooling tower performance evaluation and has been following the progress of the ERDA program.

The researchers at EPA emphasized that DW/DCT have been demonstrated as feasible technologies but that they would require significant cost and operating penalty improvements before they could be characterized as cost-effective on a national basis. Therefore, EPA strongly supports the ERDA DW/DCT efforts with its cost-reduction goals and feels that this program may produce timely and useful technology for utilities.

The Electric Power Research Institute (EPRI) has an ongoing research program in heat rejection technologies and is continuing support of several projects intimately related to ERDA's DW/DCT effort; in fact, EPRI has independently identified the ammonia loop/

deluge system as their preferred advanced cooling concept. It is not unexpected, therefore, to find that EPRI is very pleased to know that ERDA has reached the same conclusion and that EPRI would be a potential partner with ERDA in this development. EPRI has indicated that it is prepared to allocate a significant portion (up to one half) of its heat rejection budget over the next five years in support of the ammonia loop/deluge demonstration plant. EPRI also realizes that it has an important advisory role to play in the ERDA program on behalf of utilities and intends to keep abreast of all decisions and developments.

Several research organizations in two major states are also familiar with the ERDA DW/DCT program, although they have assumed different but sensible postures towards the national program. The New York Power Pool and its associated Empire State Electric Energy Research Corporation (ESEERCO) are keeping up-to-date on DW/DCT research because they feel that the siting flexibility provided by such technologies will be of significant benefit to utilities. They feel that the ERDA/EPRI efforts are useful towards this end, but that the near-term need for such technologies is not pressing in relation to other research priorities. This is, in their view, a correct assessment.

Quite a different view is held by the California Energy Resources Conservation and Development Commission, and justifiably so. Water resource management and allocation have been critical topics in California for decades, and the current drought situation in Central California serves to highlight this problem. The commission is very familiar with the ERDA program and research role, and feels that it is an appropriate federal effort; due to their pressing water situation, they are also prepared (along with EPRI) to provide fiscal support to the demonstration project as now planned.

8.3 Regulatory and Planning Agencies

The federal Environmental Protection Agency, as mentioned previously, has a distinct interest in Dry and Wet/Dry cooling technologies. Before EPA can promulgate any standards or regulations, it needs to demonstrate that the technology required to meet the standard is available, that it performs adequately, and that it is not unreasonably expensive relative to the benefits which it may produce. Thus EPA, in principle, would like to see DW/DCT technology be commercialized as a hedge against the time when strict water consumption and thermal discharge standards may be required.

EPA currently has no regulations which require dry or wet/dry cooling systems as a closed-cycle cooling technology, although evaporative cooling towers were considered when EPA issued its "no-once through cooling" directive. (EPA is aware, however, that wet/dry towers are available and are being used at several installations). EPA states that it will be several years before a national directive specifying water-conserving technology would even be considered, and that several more years would be required to develop and validate such a regulation. Thus it is unlikely that a national regulation specifying the use of dry or wet/dry cooling could be issued before 1985. A national (as opposed to state) regulation of this type may be considered unlikely before the year 2000 due to variation in the intensity of water problems throughout the nation. Nevertheless, EPA supports the development of technologies which could meet this eventual need.

The Federal Power Commission's Bureau of Power also has an interest in the development of commercial scale DW/DCT technology, as related to its Division of River Basin, Division of Licensed

Projects and its Division of Power Supply and Reliability. The Office of Energy Systems also has jurisdiction in the area of the environmental quality effects of power stations and related RD&D. Given that the new technology could be demonstrated to have adequate reliability and minimum energy penalties, the Commission would find commercial DW/DCT technology to be of benefit in their river basin system planning and project licensing studies.

The Federal Energy Administration (FEA) is mainly charged with the responsibility of maximizing electrical resources over the near term, which includes minimizing parasitic power and performance deratings and increasing the reliability of power plants. Current dry and even wet/dry cooling systems would serve to exacerbate these situations. FEA is especially concerned that ERDA be able to reduce the learning period or shakedown failures which are associated with new technologies, and that it seek to develop cooling systems with a minimum of performance penalties. FEA is also interested in any data on turbine performance and turbine life at high back pressures which may be produced by the ERDA project. (It should be noted that the wet/dry concept greatly reduces the need for turbine operation at high back pressure.)

The Bureau of Reclamation has not considered dry or wet/dry cooling technology specifically in their planning efforts (such as their Solar Energy team) but is very interested in information regarding the water savings possible with commercial wet/dry cooling systems.

The Ohio River Basin Commission, as a planning organization, is interested in any technology which promises to reduce the consumptive use of water. However, they state that in general, there will

be no problem with consumptive use of water by power plants in their area until after the year 2000, and that in lieu of legal restrictions, new technologies will need to be cost-competitive with once-through or wet tower cooling methods. Although encouraged that such research was underway at ERDA from the Ohio River Basin Commission's perspective, it was stated that the program seemed to be very long-range in nature.

Water consumption and thermal discharges are already important considerations along the Delaware River, and the Delaware River Basin Commission acknowledges that some form of water conservation technologies for power plants may become necessary after the year 1988 in its area. In a Master Siting Study performed by the Commission's Electrical Utilities Group, all but one of the projected capacity additions for the period 1974-1988 were to utilize wet cooling towers, in order to comply with thermal discharge regulations. Since the area upstream of the Delaware Water Gap is already under a restricted water development plan, it is possible that water conserving cooling technologies will be in use there before the year 2000. As such, the Commission is very interested in the progress of the ERDA DW/DCT program and in any performance and cost data which it may produce.

8.4 Fiscal Agencies

There are several federal agencies with responsibility for reviewing budgets and appropriations to research agencies; in the executive branch this task falls to the Office of Management and Budget (OMB), while the General Accounting Office (GAO) performs this task in the Congressional branch of the federal government. Research programs or projects are routinely evaluated on the basis of their merit in the public's interest, their value relative to

other federal or private industry activities and their costs relative to overall program budgeting and agency objectives.

Neither of these agencies have considered the ERDA Dry and Wet/Dry Cooling Tower Program specifically, but it is possible to describe the steps which they might take in evaluation of such a program.

A primary criteria in evaluation of most applied (as opposed to basic) research programs would be that the discounted future benefits expected from the research outweigh the identified costs of performing the research. Not all program components are subjected to this test, but large expenditures for specific projects may need to meet this requirement.

An important component of such an analysis is a well defined and appropriate set of program objectives; such objectives serve to identify the attributable benefits of the program and provide a tool for measurement of progress. Available ERDA data indicates that the ammonia/deluge demonstration project of the Battelle advanced concepts program will produce a favorable benefit/cost ratio with only a modest application of the commercialized technology during the period of 1985-2000.

A second criterion would be that federally funded research not be duplicative of other agency or private industry work, unless such a parallel effort could be expected to produce certain intrinsic benefits. In the ERDA program, the bulk of the funding has been directed toward developing advanced cooling concepts which the current market structure is apparently not prepared to provide. There is, however, some parallel private research taking place on this topic. EPRI has funded several studies which have also identified the

ammonia/deluge concept as viable, and the Foster-Wheeler Energy Company (in cooperation with McDonnell-Douglas Corporation) is pursuing a direct-condensing heat-pipe concept for utility steam condensers. Babcock and Wilcox is considering marketing the Hungarian Hoterv (Heller-Forge) technology. EPRI has indicated that it would not be able to individually fund the demonstration of the ammonia loop/deluge technology at this time, and it is believed by ERDA that the heat-pipe concept, like other direct condensing systems, may not prove workable for plants much above 300 MWe. Thus the ERDA program is thought to not be duplicative of current private activity in this field.

Yet the question of whether future private interest and research activity would produce the similar technology results is both difficult and important in this regard. If the federal program demonstrates a favorable benefit/cost ratio, there is a risk involved in not pursuing it and waiting for a private industry program; if the private effort does not materialize in a similar timeframe (which it may not, due to an unfavorable near-term Rate of Return in a commercial context) then capturable public benefits are "lost" in that they are displaced forward in time. In such considerations it is important to remember that new technology development has a minimum time lag for testing, demonstration and commercialization. If utilities are to consider advanced cooling concepts as reliable technologies this somewhat slow development process must be followed. There is also a risk involved in pursuing a research project which private industry or state governments (in lieu of a federal effort) would have produced on its own; in this case the benefits accruing

to the federal program are theoretically reduced by the public benefits attributable to the hypothetical private effort.

There is also the possibility that federal research monies will displace a private, multi-firm research 'race' which might have been more 'efficient' and which by its nature would have evaluated a greater variety of concepts than a modest federal program could investigate. However, it appears that the present cooling tower vendors do not possess sufficient available research dollars to permit this type of market competition.

It is important, however, to consider this problem of federal versus private research funding. This is a complex and to some extent unanswerable question, for it is not possible to confidently predict the future actions of firms or agencies.

A final fiscal review criterion would be that the monies requested and allocated to approved research projects are in fact sufficient, or conversely, not excessive, for the task at hand.

9. Recommendations

Federal Role in Dry and Wet/Dry Cooling Tower Research, Development and Demonstration

Criteria for Recommendations - ERDA (and its successor, the Department of Energy) has the national responsibility for directing research related to the supply, transmission, utilization, and environmental impact of energy resources. Therefore the national public interest with regard to dry and wet/dry cooling tower technology was considered for the purposes of these recommendations as the ERDA research role which would produce a commercial advanced cooling technology (in an appropriate timeframe) without undue duplication or displacement of private industry or state government efforts. This technology would be expected to return public benefits in terms of reduced pressures on valuable water resources for power plant use, as well as in reduced electricity costs relative to other dry or wet/dry cooling technologies. The presence of a federal effort in this research area should serve to bring such technology to commercial operation at a time when the described benefits would outweigh the identified costs of the program.

9.1 General Assessment

- In general, this study concludes that the DW/DCT program of ERDA is of significant merit and that continued work in this area would be in the public's best interest. Specifically--
 - The supply and demand markets for advanced concept dry or wet/dry cooling technology are quite imperfect. The suppliers, in general, are relatively small companies without significant RD&D funds; they also do not have clear incentives to pursue advanced concepts

due to the small number of established vendors and the limited opportunities for new entrants. The EPA directive for no once-through cooling was recently remanded and this can only exacerbate this situation. The utility demand for this technology also operates in an imperfect sense: the utilities receive a regulated rate of return based on their investments, thus to the extent that the extra cost burden of conventional wet/dry cooling over a potential advanced concept technology is incremental in nature, utilities may be content to stay with expensive but well-known technology, rather than to develop an advanced concept on their own.

- The general timetable of the program is appropriate since even though only a limited number of installations are expected by the year 2000, the benefit/cost ratio is still favorable from the public's perspective.
- The development of this technology may serve to create its own market. The eventual availability of advanced concept cooling technology will increase the options available to environmental regulators; given that they find such regulation to be in the public's best interest, they may issue directives requiring water-conserving technologies for utilities, creating a large market very quickly.
- The Battelle Pacific Northwest Laboratory is a competent and well respected group and is qualified to perform analytic work in this field, although their cost and design specifications may not enjoy equal acceptance. Therefore, continuing outside review and other means should be used to

enhance their credibility with utilities and vendors.

- A continuing effort should be made to involve established vendors in the RD&D program. It should be emphasized that this new technology, on balance, represents an extension to, and not an elimination of, an existing market. Such participation could provide ERDA with much insight regarding performance requirements, manufacturing and assembly procedures, as well as design "tricks."
- Problem Areas - there are several points (some of which are mentioned above) which should be addressed by the ERDA program.
 - Although net public benefits are substantial, these benefits accrue to only certain regions of the country in the near or medium term - the dry and/or water-constrained states. Although the costs on a national basis are relatively minor, this uneven allocation of benefits should be considered when future funding requirements are solicited.
 - Further demonstrations of present-day technology, such as the wet/dry Ecodyne towers to be used by Southern California Edison, are necessary only in terms of establishing their availability and cost-effectiveness with respect to possible regulatory requirements. Private activity as evidenced by the San Juan III plant of Public Service of New Mexico is proceeding and ERDA efforts should concentrate exclusively on new concepts whenever possible.
 - If not already planned, an external review of the benefit/cost and demonstration-design cost calculations should be performed. Such a review would enhance the credibility of the program from the utilities' perspective and would

facilitate the demonstration project go-ahead decision. The final report of the ammonia/deluge benefit/cost evaluation was not available at the time of this study; however, initial studies indicated a desirable benefit/cost ratio with only a limited application of the advanced concept technology.

- Participation of established vendors has not been prominent in the advanced cooling tower concepts effort and industrial firms such as Linde, Curtiss-Wright and Babcock and Wilcox have been promoting their own innovative ideas. Although valuable for their new technologies, it is not clear that these firms currently involved in the ERDA program would desire, or have the credibility, to enter the utility cooling tower business in the future. Therefore, attainment of future commercialization objectives may be affected by the continued absence of established vendor participation.

9.2 Recommendations for Technical Support

- Types of Support - ERDA, with Battelle, should continue the design and cost analysis work associated with the ammonia/deluge system planned for Pacific Gas and Electric's Kern plant in conjunction with EPRI. If the 10 MWt demonstration module is approved (as we believe it should be), ERDA should proceed with construction, testing and documentation of this facility, as planned.
- A modest amount of new technology assessment should continue; specifically, the heat pipe system as proposed by the Foster-Wheeler Company should be fully explored and tested if necessary.

- Concurrent with the construction and testing of the ammonia/deluge system, ERDA should continue to identify potential commercial users of this new technology. This continuing market assessment will provide important contacts for ERDA, as regards suggested design inputs and documentation requests from potential users and first commercial-scale site selection. Cost-sharing opportunities may also arise.
- As with the water augmentation test apparatus (WATA) being constructed at Battelle, ERDA should consider the merits of making the Kern demo site a more permanent test facility for advanced concept cooling systems (subject to the desires of Pacific Gas and Electric Co., of course). The test bed could be available to private firms or used for other government development work. Assuming that an adequate number of tests could be identified, such a facility could provide vendors (both established and potential) with an unparalleled opportunity to test and evaluate new systems at minimal incremental cost and with minor disclosure requirements. This test facility could, in fact, be operated by other groups, such as EPRI or the State of California.
- Upon successful completion of the ammonia/deluge system testing (and documentation), ERDA should actively seek an appropriate demonstration site for the first commercial scale installation of this technology. Such a site could probably be provided by one or more of the 'potential users' previously identified by the ERDA program. Technical support for the commercial scale plant should probably

be limited in nature (beyond transferral of any data or special information), and the standard vendor-user bid arrangement followed. (Fiscal support will be discussed in the next section).

- To Whom Technical Support Should be Given - ERDA, via Battelle, should continue to give technical assistance to any utilities which desire detailed information on DW/DCT systems. The demonstration of the ammonia/deluge system, its documentation and other design analysis work should continue under management of Battelle. As the project progresses with the Kern demonstration, technical support should be given to vendors as required, so that they may competitively bid on this installation. Such assistance should continue up through the construction of any commercial system. The technical (as opposed to fiscal or managerial) support phase of this project should probably terminate shortly after the commercial scale system becomes operational.

9.3 Recommendations for Fiscal Support

- ERDA should continue to fund the Battelle analysis and design work as required. However, as this program enters the demonstration and commercialization stages, ERDA should actively seek cost-sharing opportunities with the potential (and actual) users of this technology. As now planned, EPRI and the State of California (via the Energy Resource Conservation and Development Commission) will be contributing significant amounts to the Kern demonstration project, and Pacific Gas and Electric is offering the site with no special provisions. Such activities are promising and should be encouraged.

in the future testing and commercialization stages.

In fact, the proportion (though perhaps not the absolute magnitude) of ERDA's fiscal assistance should probably decrease relative to other private contributions as the program progresses. The exception may be the funding of the advanced concept test bed facility; although perhaps managed by EPRI or others, the major funding obligations for such a facility may appropriately lie with the federal government.

- Problems Areas - There is little doubt that such a research program is useful and can provide benefits to the public (and industry) in excess of its costs. But who should pay for this research? Ideally, the potential users of this technology, the dry or water-constrained utilities, should fund all such research not provided by the vendors.* However, although their basic goals may be similar, it is not immediately clear that utilities and the public share the same overall "benefits function." Thus the public (via the Federal Government) may find a research project to be beneficial when a utility (or consortium of utilities) would not, due to differing priorities, the effects of taxation or the problems of including such generic RD&D in the utility's rate base.

*It is important to note, however, that although specific 'dry' areas may make use of advanced concept cooling systems in the near future, a large part of the nation may eventually require such technology in the long-term. This further justifies, to a certain degree, a federal role in such RD&D funding.

Utilities may find such projects attractive if they can share the cost burden with others, however, as will occur in this project. The problem is to determine an equitable balancing of federal vs. user contributions, given the tendency for users to sometimes ease out of funding obligations when it is apparent that the federal government is willing to pick up the tab. This is natural and admittedly in their best interests.

Yet, advanced concept cooling technology may eventually be used nationwide, so a certain amount of federal funding may be both equitable and desirable. And in the final analysis it may well be that the small federal costs involved (probably less than 10 million dollars) are greatly outweighed by the public benefits of introducing the technology many years earlier than would occur under private development.

9.4 Recommendations for Management Tasks

- Limited ERDA participation in present-day dry and wet/dry cooling technology should be continued until such time as they are accepted by both the utility and regulatory communities as available and reliable technologies.
- The water deluge test facility should be utilized for testing promising heat transfer surfaces identified by Battelle and then opened to private firms, if possible, as a test-bed for their own developments. Appropriate schemes should be devised to permit flexible operation of this facility in reference to test data dissemination.
- The heat pipe concept being pursued by the Foster-Wheeler Energy Company should continue to be reviewed in terms of

its significance relative to the ERDA/EPRI selected ammonia/deluge advanced concept.

- ERDA should continue to support Battelle for design analysis, construction and testing of the ammonia/deluge concept module at the Kern plant site of Pacific Gas and Electric.
- As construction of the Kern module nears completion, ERDA should begin a process of identifying and contacting potential near-term users and vendors of the technology, both for test procedure suggestions and to facilitate effective data dissemination. This group may eventually prove to be a source of cost-share funding as the program progresses.
- Near the end of the 2-3 year demonstration module test period, ERDA should initiate a program which will result in a commercial scale system installed by a vendor at an appropriate utility site. ERDA's role should shift in this phase from leadership to one of consultant and risk sharer (some dollar assistance), with vendors supplying the bulk of the commercialization design effort.
- ERDA should consider the eventual conversion of the Kern demonstration site to a permanent test-bed facility for the use of private firms or other research organizations. It would be appropriate for ERDA to provide the technical and management support necessary to affect this conversion. ERDA's long term role at this facility should be advisory in nature, with operation of the test-bed facility performed by EPRI or other appropriate groups.

9.5 Recommendations for Further Research - The Federal Role in Dry and Wet/Dry Cooling Tower Research, Development and Demonstration

- A. A Related Market's Analysis - this project would explore the potential usefulness of advanced concept heat exchange systems and components in markets other than the domestic electric utility industry. This may enhance the national benefits of the ERDA program. These related markets could include:
- Geothermal energy utilization - (electric) which occurs mainly in dry areas
 - Solar energy utilization - for central station concepts in dry areas, or Total Energy Systems for community scale
 - European and Mid-East markets - for water-short areas with industrial growth (also may include other developing countries). There may be some potential for cost-sharing of the DW/DCT effort from contacts developed in these surveys.
 - Heating and Refrigeration Applications - including on-site Total Energy Systems, integrated utilities and air-conditioning.
 - Industrial Processes - refineries, plastics, chemicals, etc.
- B. Related RD&D Program Assessment - Project management problems notwithstanding, the ERDA Dry Cooling Program should assess other RD&D efforts which are found to be closely related to (or have common interests with) the DW/DCT projects

(such as the geothermal program, OTEC, bottoming cycle research) on a continuing basis. This may determine if jointly funded or directed programs could 1) assess a broader range of technical concepts 2) achieve more timely results 3) and share informational results, thereby producing program cost savings and/or allowing each program to perform more RD&D than otherwise possible.

- C. Regulatory Assessment - As the project moves into the demonstration (pre-commercial) stage, it is important that ERDA develop a working relationship with other federal and state agencies which have a direct interest in the availability or impact of advanced concept dry and wet/dry cooling technology. Such contacts would permit assessments of the performance and safety requirements for use of the proposed technology, the need for and value of the proposed technology from an environmental and regulatory standpoint, and would facilitate adoption of reasonable federal and state standards as they may pertain to the performance, cost and availability of DW/DCT technology.
- D. A Test Facility Favorability Analysis - this project would investigate the precedents for federally funded, commercial-oriented test-bed facilities (of various types), and would delineate the benefits and potential problems of such an approach for the ERDA Wet/Dry Cooling Tower project. It would be of utmost importance to carefully define the legality of operation of such a facility if test data were not to be released due to proprietary status provisions. The relative costs and benefits of various operating modes would be assessed, and an informal survey of potential

participants would be initiated.

- E. Assessment of the Feasibility of a Dry (or water constrained) Utilities Consortium - This group (made up of utilities in dry, water constrained or site-poor areas, appropriate public utility commissions and other relevant regulatory bodies) could be an appropriate vehicle to assist ERDA in the final commercialization stages of its DW/DCT program. It may be expected that such a group (working perhaps through EPRI) would bear a significant share of the costs and development work needed to bring the preferred advanced concept technologies to commercial scale, through contributions of money, skills or test sites.

Note: The distinct possibility that environmental regulators would begin to require DW/DCT (if available) on a technical and economic basis will serve to sharply divide utilities over participation in such a group. Those who feel that they may come under such regulations anyway should be eager to develop a lower cost technology and should participate. Others would see development as creating the opportunity for unwanted and costly cooling system directives and would therefore discourage such a consortium. The Utilities Water Act Group (which successfully fought the EPA "off stream" directive) could be a well-organized and formidable opponent to the formation of such an interest group. Vendors, however, may view this as an excellent opportunity to expand their markets and might participate in the program to a greater extent than at present.

10. Glossary of Terms

BNWL -- Battelle Pacific Northwest Laboratory

DHR -- Donovan, Hamester & Rattien, Inc.

DW/DCT -- Dry and Wet/Dry Cooling Towers

EPA -- Environmental Protection Agency

EPRI -- Electric Power Research Institute

ERDA -- Energy Research and Development Administration

GWe -- giga watts, electric (10^9 watts)

MIT -- Massachusetts Institute of Technology

MWe -- megawatts, electric (10^6 watts)

MWt -- megawatts, thermal

OTEC -- Ocean Thermal Energy Conversion

RD&D -- Research, Development and Demonstration

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