

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE AS MUCH
INFORMATION AS POSSIBLE

(NASA-CR-168805) REGIONAL APPLICABILITY AND N82-22664
POTENTIAL OF SALT-GRADIENT SOLAR PONDS IN
THE UNITED STATES. VOLUME 1: EXECUTIVE
SUMMARY (Jet Propulsion Lab.) 23 p Unclas
HC A02/MF A01 CSCL 10A G3/44 09687

Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States

Volume I: Executive Summary

E.I.H. Lin

March 1, 1982

Prepared for
U.S. Department of Energy
and
U.S. Department of Defense
Operations Research Department
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 82-10, VOLUME I)

Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy and the U.S. Department of Defense, Operations Research Department, Washington, D.C., through an agreement with the National Aeronautics and Space Administration.

The JPL Solar Ponds Project is sponsored by the U.S. Department of Energy and is part of the Solar Thermal Program to develop solar pond technology.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ABSTRACT

A comprehensive assessment is made of the regional applicability and potential of salt-gradient solar ponds in the United States. The assessment is focused on the general characteristics of twelve defined geographic regions, while neglecting site-specific details, and includes: a survey of natural resources essential to solar ponds; an examination of meteorological and hydrogeological conditions affecting pond performance; the identification of potentially favorable pond sites; calculation of regional thermal and electrical energy output from solar ponds; a study of selected pond design cases; an evaluation of five major potential market sectors in terms of technical and energy-consumption characteristics, and solar-pond applicability and potential; a detailed economic analysis considering relevant pond system data and financial factors; and a comparison of solar-pond energy costs with conventional energy costs.

The assessment concludes that, excepting Alaska, ponds are applicable in all regions for at least two market sectors. Compared with conventional energies, solar ponds will generally be able to attain near-term economic viability in several southern, high-insolation regions. Total solar pond energy supply potential in the five market sectors examined is estimated to be 8.94 quads/yr by the year 2000, approximately 7.2% of the projected total national energy demand.

ACKNOWLEDGMENTS

The work reported herein was performed through NASA Task Order RD 152, Amendment 272, and was sponsored by the United States Department of Energy under IAA DE-AT04-80AL13135 and by the Department of Defense, Operations Research Department, Washington D.C. The JPL study team wishes to acknowledge the support of the U.S. Department of Energy and the U.S. Department of Defense. The Benham Group of Oklahoma City, Oklahoma, the Ormat Turbines, Ltd. of Israel, and Utah State University (Drs. J. P. Riley and J. C. Batty) have each performed a subcontract in support of this study. Valuable comments and/or guidance were provided by W. A. Menard, J. C. Becker and J. L. Hesse of JPL, S. Sargent of DOE and K. Meyer of Los Alamos Scientific Laboratory.

CONTENTS

1.0	INTRODUCTION	1
2.0	FINDINGS	2
2.1	RESIDENTIAL, COMMERCIAL AND INSTITUTIONAL BUILDINGS SECTOR	2
2.2	INDUSTRIAL PROCESS HEAT SECTOR	5
2.3	AGRICULTURAL PROCESS HEAT SECTOR	5
2.4	ELECTRIC POWER SECTOR	7
2.5	DESALINATION SECTOR	10
3.0	SUMMARY	10
4.0	CONCLUSIONS AND RECOMMENDATIONS	14

Figures

1.	Regional Applicability and Potential of Solar Ponds: Residential, Commercial and Institutional Building Applications (3.27 quads/yr)	4
2.	Regional Applicability and Potential of Solar Ponds: Industrial Process Heat Applications (0.82 quads/yr)	6
3.	Regional Applicability and Potential of Solar Ponds: Agricultural Process Heat Applications (0.76 quads/yr)	8
4.	Regional Applicability and Potential of Solar Ponds: Electric Power Generation (3.46 quads/yr)	9
5.	Regional Applicability and Potential of Solar Ponds Desalination: (0.63 quads/yr)	11

Table

1.	Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States	12
----	---	----

EXECUTIVE SUMMARY

1.0 INTRODUCTION

This report documents a study conducted during August 1980 through November 1981 to assess salt-gradient solar pond resources and to determine their applicability and potential in the United States. The study was funded by the Department of Energy, with partial support by the Department of Defense. Its participants included a JPL team and two sub-contractors: the Benham Group of Oklahoma City and Ormat Turbines, Ltd. of Israel.¹

The study proceeded by first conducting a nation-wide survey of the four natural resources essential to solar ponds (i.e., sunshine, land, water and salts/brine) and the various meteorological and hydrogeological conditions affecting pond performance (e.g., ambient temperature, evaporation, soils, and winds). Locations possessing abundant resources and favorable conditions were identified. Twelve geographic regions were defined, based on patterns of insolation level, water and salts/brine availability, ambient temperature distribution and other climatic variables. This regional assessment approach allowed comprehensive coverage of the entire United States while neglecting site-specific details.

Regional thermal and electrical energy output from solar ponds were calculated, using a JPL-developed solar pond performance model, based on pertinent data at representative sites within the regions. Pond subsystem and energy distribution subsystem design parameters were studied for selected cases.

Five major potential market sectors were addressed: the residential, commercial and institutional buildings sector, the industrial process heat sector, the agricultural process heat sector, the electric power sector and the desalination sector. Technical and energy-consumption characteristics of each market sector were scrutinized, and solar pond applicability and potential in each sector were examined.

A detailed economic analysis was then conducted which took into account regional energy output, various solar-pond capital, Operations and Maintenance (O&M) cost data and design considerations, and a number of financial factors (e.g., application-specific discount rates, accelerated depreciation schedule, tax rates, inflation rate, investment tax credits, escalation rates for capital, O&M and fuel costs, etc.). These inputs were used to compute solar-pond energy costs, which were in turn compared to conventional energy costs.

¹The Benham Group conducted a survey and analysis of land availability and land values in the residential, commercial and institutional buildings sector, and Ormat performed case studies to determine solar pond design and performance parameters for a series of specified applications.

Finally, solar-pond regional applicability and potential were qualitatively and quantitatively assessed by market sectors. Supported by an extensive data base, the results reveal a wide applicability and promising energy supply potential for solar ponds in the United States.

2.0 FINDINGS

Solar pond technology is considered applicable to a particular market sector in a specified region if (1) the need exists for low temperature (less than 200°F) thermal energy or electric power; (2) the necessary resources are available; (3) the pertinent physical conditions are suitable; and (4) pond energy is economically competitive with alternative energy sources before the year 2000. Site-specific factors such as environmental and institutional constraints were not considered when assessing the regional applicability of pond technology. Solar pond potential in the applicable regions is defined as the solar pond energy-producing capacity that has not yet but may become a reality by the year 2000. The assessment of solar-pond potential allows for market sector expansion but not for market penetration by pond technology because the latter depends on political and economic issues whose evolution over the next two decades cannot be accurately predicted.

Regional applicability and potential of solar ponds in the various market sectors are summarized in what follows.

2.1 RESIDENTIAL, COMMERCIAL AND INSTITUTIONAL BUILDINGS SECTOR.

With the exception of Alaska, solar ponds can provide thermal energy at sufficiently high temperatures for building space heating and domestic water heating in all regions. Alaska's low insolation and low ambient temperatures prevent uninsulated solar ponds, which are not equipped with reflectors to enhance solar collection, from producing thermal energy at temperatures higher than 45°C. Space cooling using solar ponds is feasible in principle but requires further research and development to improve its performance.

The need for thermal energy in space heating/cooling and domestic water heating exists in every state and region. Generally, building heating loads decrease from north to south, whereas the converse is true for cooling loads. Water heating loads tend to be uniform throughout all regions. In the north, deeper ponds are required to store thermal energy collected in the summer for use in space heating during the winter. In the south, shallower ponds will suffice as winter heating load is light and summer cooling load peaks in phase with insolation.

Because of heat loss considerations, a very small pond serving an average-size single-family dwelling is not practical. However, a one-half to several acre pond serving a group of single-family houses, a multi-family dwelling complex, a sizable commercial or institutional building, or a district comprising a large number of various building types is more appropriate.

The availability of low-cost land in the proximity of end-use buildings will be a limiting factor, as vacant land is scarce and costly in most developed areas. The number of ponds retrofitted in the developed areas is therefore expected to be relatively small. Construction of the majority of solar ponds is expected to occur in to-be-developed areas, where ponds can be incorporated during planning and design phases.

Insolation level, initial pond capital cost and discount rate are the three most critical factors affecting the ability of ponds to compete with alternative energy sources. If a discount rate of 11% is assumed, then thermal energy from ponds for building heating/cooling and water heating applications will be competitive with most conventional fuels in the Southwest, Puerto Rico, and Hawaii regions. If capital costs are sufficiently low, they will also be competitive in the remaining regions. However, if a discount rate of 20% is assumed, then ponds will be economically competitive in most of the high and moderate insolation regions only if low capital costs are attainable.

Solar-pond potential in the residential, commercial and institutional buildings sector is limited by land, not need. A conservative estimate of pond potential utilizes the pond-suitable land acreage obtained by the Benham Group for the to-be-developed areas (as determined by the local zoning ordinances.) The total U.S. pond potential in the buildings sector is estimated to be 3.27 quads/yr, which amounts to less than 12% of the projected energy needs for space heating/cooling and water heating in the year 2000. The Red River region (see Figure 1) leads others with a potential of 1.08 quads/yr because it has the greatest acreage of pond-suitable land and relatively high pond performance. Although the Great Lakes region has the greatest thermal energy needs (almost 2.5 times those of the Red River region), it possesses only a modest quantity of pond-suitable land, and a relatively low level of pond energy output. Consequently, pond potential in the buildings sector for the Great Lakes region is low. However, the rate of future development may not follow the current ranking of estimated potential. The northern-heating and southern-cooling emphases and differential readiness of ponds for heating and cooling are bound to affect the course of pond development in the buildings sector.

Figure 1 shows, for the buildings sector, the regions favoring pond development, the estimated regional potentials, and those regions where near-term economic viability of pond energy is attainable.

2.2 INDUSTRIAL PROCESS HEAT SECTOR

Need for thermal energy below 200°F within the manufacturing Sector [Standard Industrial Classification (SIC) Code Categories 20-39] is concentrated in the states of California and Washington, most of the Red River region, Gulf Coast and Atlantic Northeast regions, part of the Tennessee Valley region, and all of the Great Lakes region. Food, furniture, paper, chemicals, leather, stone/clay/glass and primary-metals processing are among the major industries to which solar ponds can be suitable energy suppliers. Using solar ponds for preheating in the higher-temperature processes has not been considered in this study as appropriate conservation measures such as waste heat utilization may be more readily and economically implemented.

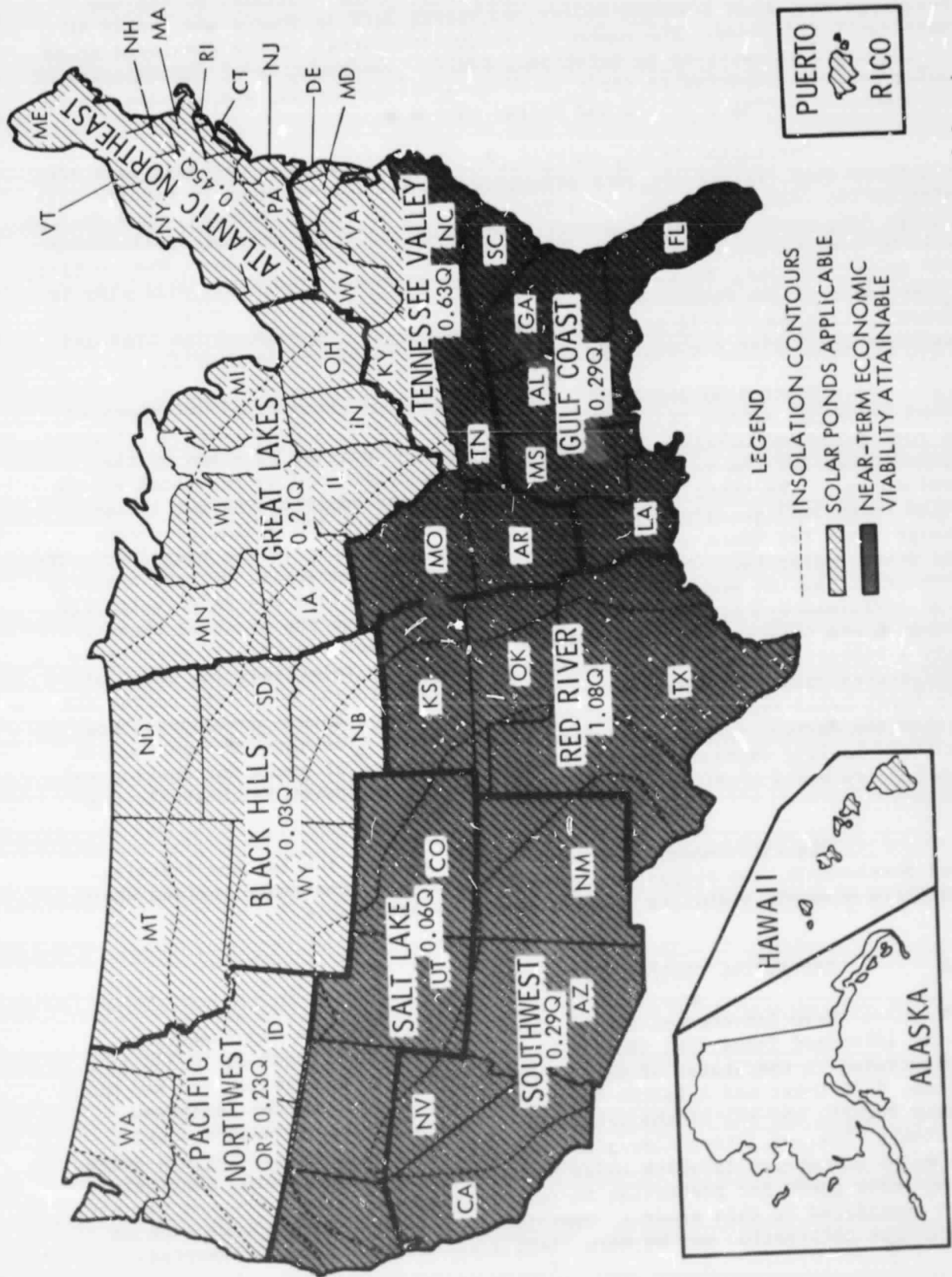


Figure 1. Regional Applicability and Potential of Solar Ponds: Residential, Commercial and Institutional Buildings Applications (3.27 quads/yr)

The majority of solar ponds in the industrial sector will be relatively small. Hence, salts and water resources are not expected to be as limiting as land. Land limitation will likely result in fewer ponds constructed in SMSAs (Standard Metropolitan Statistical Areas) than in non-SMSAs. Many of the more than 176,000 existing impoundments may be suitable for conversion into solar ponds.

Near-term economic viability is expected in California and most of the Red River and Gulf Coast regions. Early application of solar ponds is more probable in the food processing and chemical industries. Within the Great Lakes, Tennessee Valley and Atlantic Northeast regions, near-term economic viability will be achieved only if low capital costs and favorable financial conditions can be obtained.

Assuming that all of the manufacturing thermal energy needs (less than 200°F) in the non-SMSAs, and only half of those in the SMSAs are to be met by solar ponds, industrial pond potential in the United States is estimated to be 0.82 quads/yr by the year 2000. Preheating use of solar ponds and nonmanufacturing industrial processes such as mining are not included in this estimate. The pond-applicable regions, estimated potentials and areas of near-term economic viability are depicted in Figure 2.

2.3 AGRICULTURAL PROCESS HEAT SECTOR

Agricultural activities take place throughout most of the country. Only a few states have limited agricultural production due to geological or climatic restrictions. Solar ponds can supply thermal energy to a number of agricultural processes: crop drying, livestock brooding, livestock waste disposal, space and water heating for livestock shelters, greenhouse conditioning, and farmhouse space and water heating. Irrigation pumping also consumes a significant fraction of agricultural energy, and solar ponds should be able to provide electricity or shaft power for this purpose.

Ponds will not be widely applicable in the states of Nevada, Wyoming, North Dakota and those within and neighboring the Atlantic Northeast region primarily because of their limited needs for agricultural thermal energy. The applicable regions are distributed throughout the remainder of the country. However, more ponds for agricultural uses are expected, based on need and resource availability, in the Red River, Great Lakes, and Southwest regions. The Red River region ranks first in having an agricultural thermal energy need that can be met by solar ponds, followed by the Great Lakes and Southwest regions.

Farm ponds are expected to be moderately sized. A one-acre pond will be able to supply most of the thermal energy needs of a several-hundred-acre farm. Locally occurring salt resources are not a crucial factor. Demand on water resources will not be overly severe. Locating a several-acre pond on a large farm should not constitute a problem. Appropriate pond liner or groundsealer will be required in most cases, however, to guard against possible contamination of productive land.

A multi-purpose farm pond is envisioned as an integral part of future large farm landscape built near the farm houses, animal shelters, greenhouses, and crop processing machinery. The high-yield period of a pond (i.e., fall) coincides with the high energy-demand period of most farms as crop processing activities occur most frequently around this time.

Near-term economic viability for farm ponds is likely to occur in the higher insolation regions. Significant expansion of the U.S. agricultural sector is not expected, and the total national pond potential is estimated at 0.76 quads/yr by the year 2000. Figure 3 indicates the applicable regions for agricultural ponds, along with the estimated regional potentials and areas of near-term economic viability.

2.4 ELECTRIC POWER SECTOR

Solar pond application in the electric power sector is perceived to be limited by resources rather than need. Most of the United States is or can become connected to utility grids, and the grids presumably can absorb any amount of power that is generated by solar ponds.

Solar ponds which generate electric power will be constructed mostly on a large scale (tens or hundreds or thousands of acres in area), and on sites where the essential natural resources (sunshine, land, salts and water) are available at low or no cost. Many of these sites are likely to be situated away from population centers. The design, construction, operation and maintenance of these ponds will be significantly different from those of thermal ponds. The physical, economic, environmental, and other factors that affect the installation and performance of these ponds will also be considered from a different perspective than thermal ponds. Smaller ponds built to generate electricity for specific community use or industrial plant applications can also be expected, but the various technical and economic considerations for these may deviate from the large-scale ponds. Existing impoundments may receive attention for conversion into solar pond power plants.

The evaluation of natural resources, particularly water and salts/brine, provided information needed for siting potential electricity-generating ponds. The applicable regions are shown in Figure 4, where specific potential sites are also indicated.

For a commercial size solar pond power plant (e.g., 600 MWe), present or near-term economic viability is attainable in the Southwest, Puerto Rico, Hawaii, Salt Lake, Red River, and Gulf Coast regions. For a smaller plant, on the order of 5 MWe, the per kilowatt installed capital cost will be increased, and regions where pond power is economically competitive with alternatives will be restricted.

Estimated on the basis of conservative exploitation of the available resources, the national electric power pond potential is 3.46 quads/yr. A significant fraction of this is contributed by the Red River region. Note that small-scale electricity-generating ponds, such as those employable in the

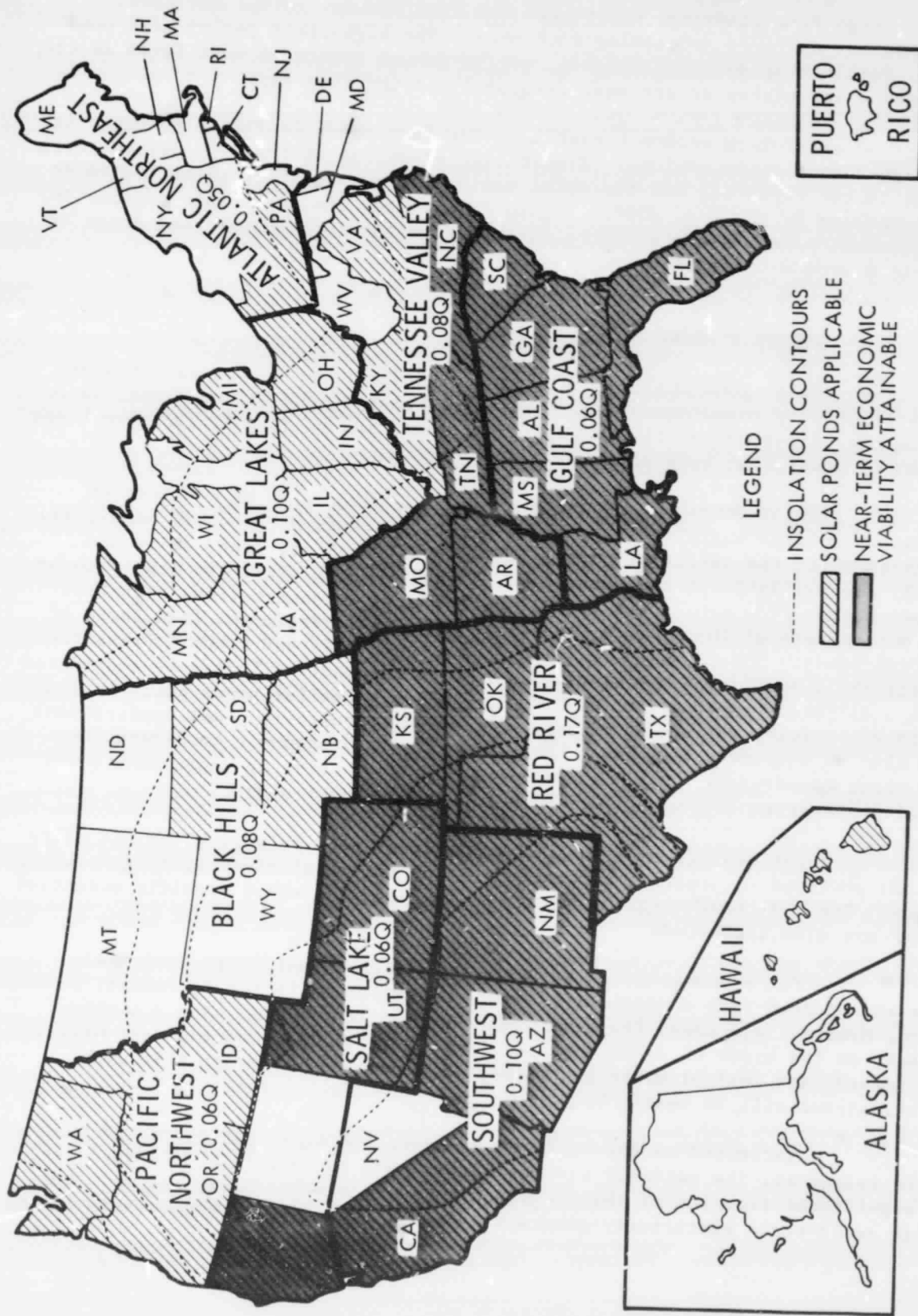


Figure 3. Regional Applicability and Potential of Solar Ponds: Agricultural Process Heat Applications (0.76 quads/yr)

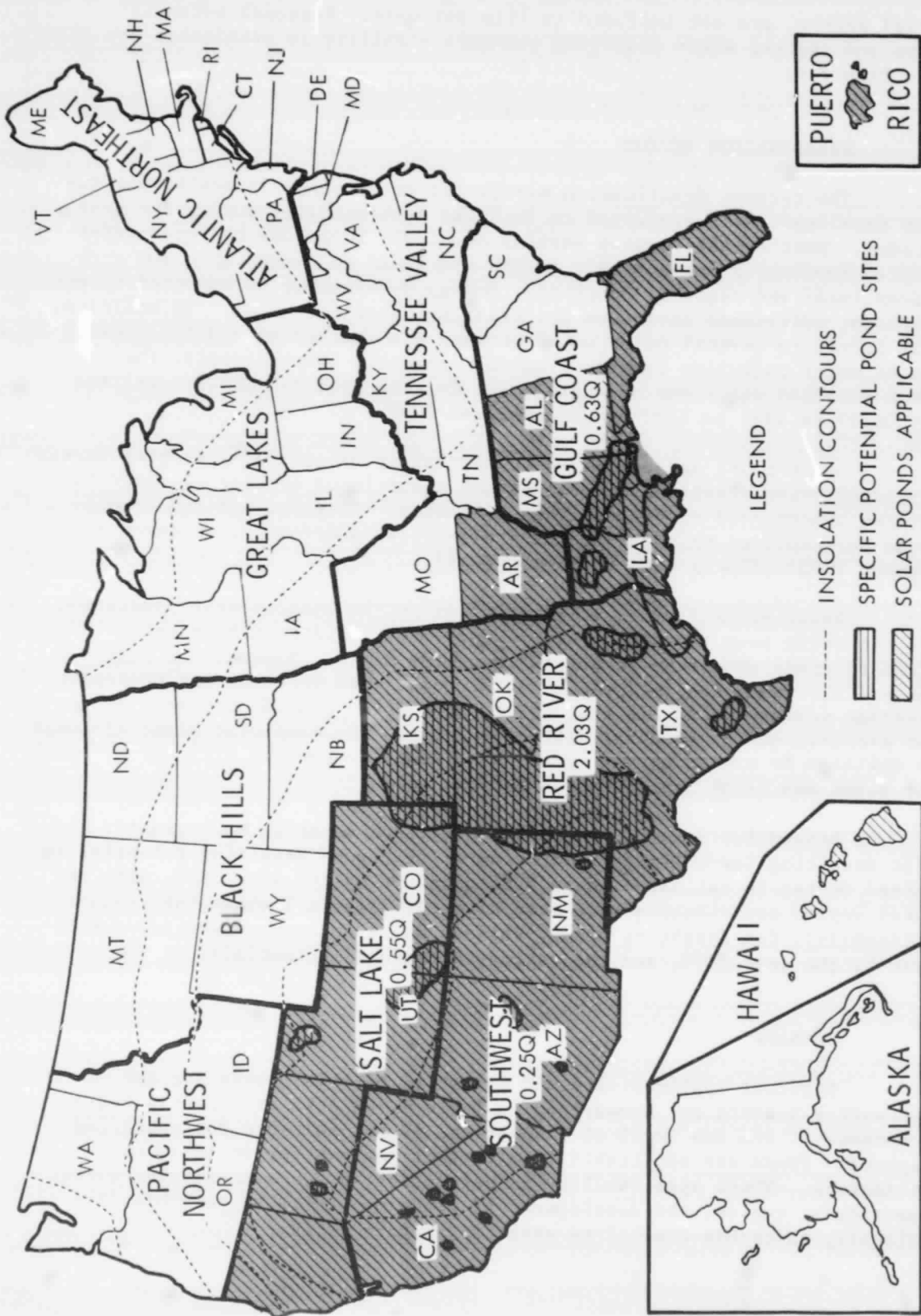


Figure 4. Regional Applicability and Potential of Solar Ponds: Electric Power Generation (3.46 quads/yr)

industrial sector, are not included in this estimate. Regional potential estimates and regions where near-term economic viability is attainable are also shown in Figure 4.

2.5 DESALINATION SECTOR

The current desalination market for solar ponds is small, but the need for desalination is projected to increase substantially during the next two decades. Most of the country west of about 96° longitude has been water deficient. Population and economic growth continues to demand more and more water from local and regional supplies. Energy development is expected to put a significant additional strain on the existing water resources. In addition, salinity levels in several major water streams are increasing and the growing problem of water pollution is affecting most regions. Consequently, the demand on desalted water has been projected to grow from 273 million gallons per day (mgd) in 1981 to 2500 mgd in the year 2000.

Solar ponds are perceived to be capable of providing thermal energy to the distillation desalination process and electric or mechanical power to the reverse osmosis and electrodialysis processes. To date, limited studies have been performed on this particular application, and further Research and development (R&D) efforts need to be conducted.

Solar ponds for desalting purposes may be located near population centers, in which case land and other resource constraints must be satisfied, or in remote areas where the requisite resources may be abundant. A number of options are available for integrating solar ponds into desalination processes. An advantage worthy of note is that while solar ponds provide thermal, mechanical or electric energy to desalination processes, the desalting plant effluent can be utilized by ponds, resulting in cost reduction both in effluent disposal for the plant and brine concentration for the pond.

Demand for desalting high salinity feed water is much greater than that for desalting low-salinity feed water. Solar-pond desalting potential in the United States is estimated to be 0.63 quads/yr by the year 2000, with the Southwest region contributing more than a third. Figure 5 shows the regions of applicability for desalting ponds, regions where economic viability can be achieved by the year 2000, and the estimated regional potentials.

3.0 SUMMARY

Regional applicability and potential of solar ponds for the various market sectors are summarized in Table 1. Alaska is the only region that, because of its low level of insolation, is not suitable for operating solar ponds. Ponds are applicable in all other regions for at least two market sectors. Where applicability is not indicated for a particular market in a particular region, the development of ponds may still be possible if exceptionally favorable conditions exist on certain sites.

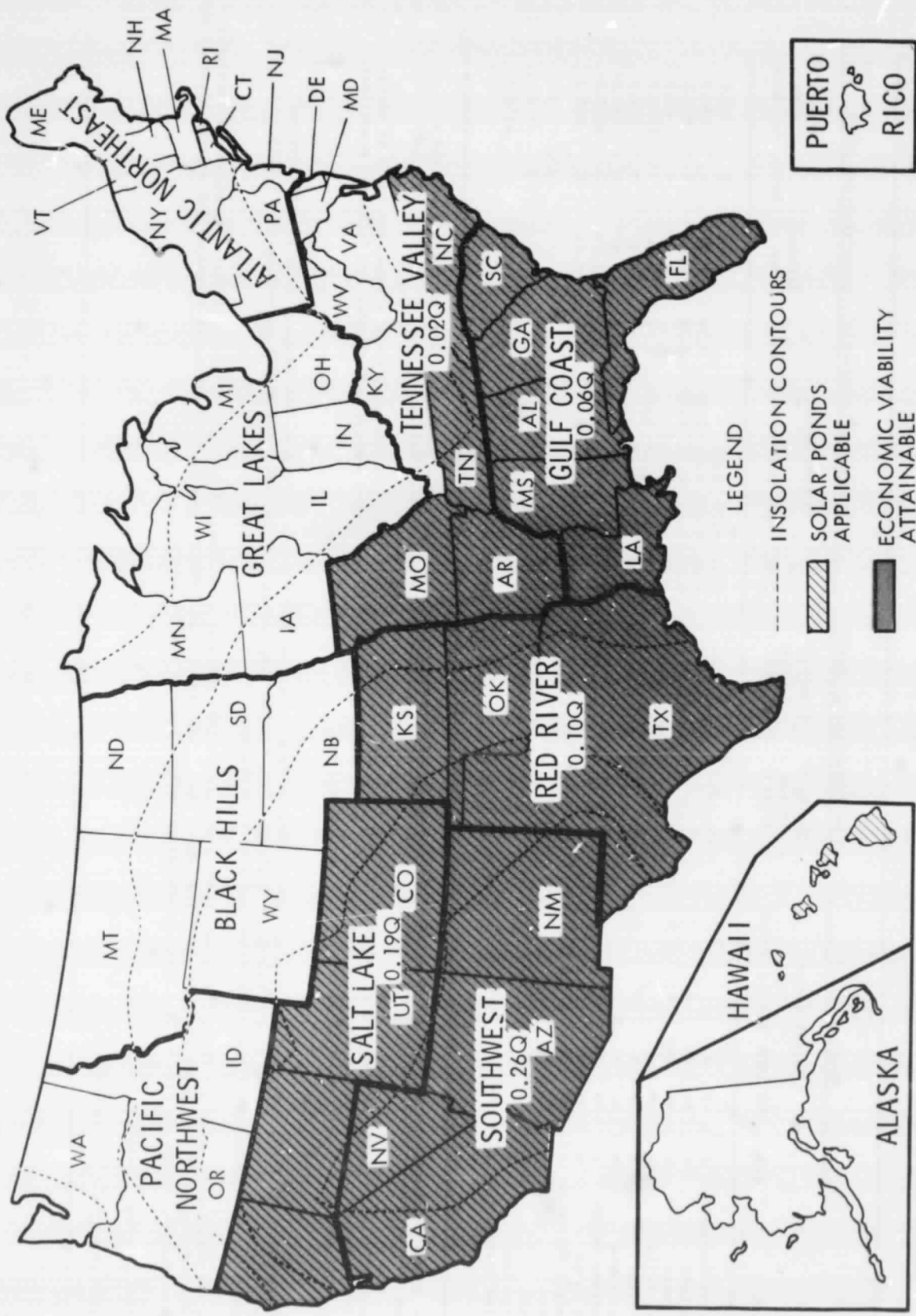


Figure 5. Regional Applicability and Potential of Solar Ponds: Desalination (0.63 quads/yr)

Table 1. Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States

Region	Applicability ^a				Delivered Energy Cost ^b			Energy Supply Potential, quads/yr (year 2000)					Total Pond Area, 10 ³ acre
	Bldg.	Market Sector			Thermal ^c Energy \$/MBtu	Electric ^d Energy ¢/KWh	Bldg.	Market Sector		Regional Sum	Rank		
		IPH	APH	Elect.				Elect.	Desal.				
Pacific Northwest	x	xx	x		11.7-38.3	14.1-50.9	0.23	0.03	0.06	0.32	8	82.9	
Salt Lake	x	xx	xx	x	8.0-25.9	10.0-30.4	0.06	0.02	0.06	0.19	4	706.2	
Southwest	x	xx	xx	x	6.0-19.5	8.5-23.5	0.29	0.03	0.10	0.26	3	307.5	
Black Hills	x	xx	xx		14.7-46.3	18.0-69.0	0.03	0.02	0.08	0.13	9	42.5	
Red River	x	xx	x	x	8.3-26.6	11.2-34.8	1.08	0.06	0.17	2.03	1	1301.5	
Great Lakes	x	x	x		16.7-54.7	21.5-83.9	0.21	0.28	0.10	0.59	7	218.5	
Tennessee Valley	x	xx	xx	x	9.7-31.3	12.8-44.0	0.63	0.14	0.08	0.02	5	186.3	
Gulf Coast	x	xx	x	xx	9.0-28.7	11.8-39.1	0.29	0.13	0.06	0.06	2	1057.8	
Atlantic Northeast	x	xx	xx	e	18.5-61.9	25.9-104.0	0.45	0.11	0.05	0.61	6	252.1	
Alaska		e	e	e									
Hawaii	x	x	x		6.6-21.0	9.0-26.2	f	f	f	f	f	f	
Puerto Rico	x	x	x		6.5-19.5	8.7-24.5	f	f	f	f	f	f	
United States	x	x	x	x			3.27	0.82	0.76	3.46	8.94	4155.3	

^aThe symbol x indicates that solar ponds are applicable in the entire region; xx indicates applicability in parts of the region; and a blank indicates that, disregarding the exceptional cases, solar ponds are not applicable in the region.

^bCompared with the costs of energy from conventional sources such as natural gas, coal-fired and oil-fired power plants, the costs of energy delivered from solar ponds are generally competitive in the high insolation regions and under reasonable technical and financial conditions. Detailed comparisons are presented in the text of the report.

^cEnergy costs are for a 1990 pond start-up and are in 1981 dollars. The cost range covers a capital cost range of from \$31/m² to \$87/m² and a discount rate variation from 11% to 20%. Inflation rate = 7.2%. Capital escalation rate = 7.2%. O&M escalation rate = 9.3%. Investment tax credit rate = 10%. Sum-of-years-digits depreciation.

^dSubbar electricity costs are for a 1990 pond start-up and are in 1981 dollars. The lower figures are based on capital cost estimates developed for a 600-MWe solar pond power plant at the Salton Sea. The higher figures are based on capital cost estimates developed for a 5-MWe plant at the same location. Discount rate = 11%. Other financial parameters are the same as above.

^eSolar pond not feasible.

^fData insufficient for estimation.

Costs of delivered energy from solar ponds are also included in Table 1. The costs are in 1981 dollars and are for ponds with a 1990 start-up schedule. The start-up date does not affect energy costs significantly. For example, these costs will be reduced by 1.0% to 1.5% if a 1985 start-up date were to be considered. With respect to the thermal energy costs, the low figures in the range are associated with a pond capital cost of \$31/m² and a discount rate of 11%, while the high figures in the range are associated with a pond capital cost of \$87/m² and a discount rate of 20%. The busbar electric power costs are based on a discount rate of 11% with the low figures based on capital cost estimates developed for a 600-MWe commercial-size solar pond power plant at the Salton Sea, and the high figures related to a 5-MWe plant at the same location. The other pertinent financial factors are: inflation rate = 7.2%; O&M escalation rate = 9.3%; capital escalation rate = 7.2%; system lifetime = 20 years; construction time = 2 years; miscellaneous expense rate = 2.25%; investment tax credit rate = 10%; depreciation by the sum-of-years-digits method; and the various local tax rates as appropriate for the regions (which range between 44% and 51%).

When solar ponds are compared with natural gas for industrial thermal applications (using a discount rate of 20%), no solar ponds will be competitive in any region during the next two decades within the capital cost range considered. For municipal thermal applications (using a discount rate of 11%), ponds will be competitive for a subset of capital costs and regions after 1990. This comparison will have to be reexamined if deregulation of natural gas price takes place.

When a 250-acre solar pond power plant (producing 5 MWe nominal in the Southwest region) is compared with a small (8-MW) new oil-fired facility, the solar pond power plant is competitive in the Southwest, Hawaii, and Puerto Rico regions within the capital cost range considered. If the capital costs can be held below \$50/m², then ponds are also competitive in the Salt Lake and Red River regions, and nearly competitive in the Gulf Coast and Tennessee Valley regions.

When a 26,400-acre pond (producing 600 MWe nominal in the Southwest region) is compared with a coal-fired power plant, the pond is competitive in the Southwest, Red River, and Hawaii regions and not competitive in the Black Hills, Great Lakes, Atlantic Northeast, and Alaska regions. In all other regions, the solar pond power plant can be competitive under specific time horizons and capital cost ranges. In general, under proper technical and financial conditions, solar ponds can attain near-term economic viability in the southern high-insolation regions. This is as expected because higher solar intake results in higher pond energy yield and lower energy cost.

The energy supply potentials of solar ponds in the year 2000 are also tabulated in Table 1 by region and by market sector. Insufficient data are available to enable estimation for the Hawaii and Puerto Rico regions. Although quad numbers will be small for these two small regions, high pond performance and the apparent availability of resources are expected to make ponds significant energy suppliers to meet the local needs. The Red River region ranks the highest in pond potential, 3.44 quads/yr, for a combination

of reasons: abundant resources, strong energy demand, relatively high insolation, and suitable climatic and hydrogeological conditions. The Gulf Coast and Southwest regions rank number 2 and number 3, respectively; both have very favorable conditions to support solar ponds development. Situated in the sun belt, both regions have experienced and will continue to experience healthy economic expansion. Most of this country's first commercial solar pond facilities can be expected in the Red River, Gulf Coast and Southwest regions.

The Salt Lake region ranks number 4 with a significant contribution from the Great Salt Lake, whose electric power generating potential tops the nation's inland water bodies. The Tennessee Valley ranks number 5 with favorable conditions for ponds in almost every market sector. The Atlantic Northeast region follows in the ranking primarily because of a large potential in the residential, commercial and institutional buildings sector. This is because the region is highly developed, and the pond-suitable-land acreage in the areas to be developed is second only to that for the Red River region. However, considering the low insolation level and cold winters prevailing in the region, and the region's slower economic growth patterns, additional engineering and economic considerations will be required to realize this potential in the buildings sector. The Great Lakes region ranks number 7; although the agricultural and industrial activities are rather brisk in comparison with other regions, the relatively low insolation level renders application of solar ponds in the other market sectors less attractive. The Pacific Northwest and Black Hills regions are two of the least attractive regions for solar ponds. The explanation lies in low insolation, unfavorable climatic or geological conditions, meager pond resources, and low energy demand.

The total energy supply potential of solar ponds for the United States in the year 2000 is estimated at 8.94 quads/yr. This amounts to 7.2% of the projected national energy demand for that year. An estimated four million acres of solar ponds will be required to produce 8.94 quads/yr. This total pond area is slightly less than four times the area of the Great Salt Lake, a small quantity compared to the vast expanse of the country.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have resulted from the study:

- (1) Abundant resources exist in the United States for developing salt-gradient solar ponds to supply electric power and low-temperature thermal energy. Climatic and hydrogeological conditions are suitable for operating solar ponds in most regions of the country. Five major market sectors display energy demand characteristics that are compatible with solar ponds. Near-term economic viability is attainable for the pond technology in several regions and markets. The energy supply potential of solar ponds in the year 2000 is estimated at 8.94 quads/yr, 7.2% of the projected total national energy demand.

- (2) Solar pond potential is high. Actions should be taken on the federal, local and private sector levels to develop this potential. In the initial commercialization stage, the federal government should play an active role in providing the local government and private sectors with adequate incentives to stimulate deployment of solar ponds. Co-funding prototype pond projects and strongly supporting large-scale field experiments and important R&D activities are examples of recommended federal involvements.

Local government and private-sector users are the direct beneficiaries, and should take positive steps to bring about early commercialization of solar ponds.

- (3) Regions deserving particular attention are the Red River, Gulf Coast, Southwest and Salt Lake regions, where the pond potential is the highest, the resources are the most abundant, and the energy demands are the greatest. Specific sites within these regions are, for example, the Salton Sea, the Great Salt Lake, Permian Basin, the Gulf Coast salt domes, Paradox Basin, Supai Basin, the Red River chloride control zones, Galveston Bay, Owens Valley, San Diego Bay, etc.
- (4) The electric power production potential of solar ponds is enormous. At an estimated 3.46 quads/yr, electric power ponds represent about 39% of the national pond potential. The recent Israeli success in generating electricity with ponds and the knowledge of this sizable U.S. potential should stimulate increased emphasis in this market.
- (5) The pond potential for space heating/cooling and water heating in the residential, commercial and institutional buildings sector is also very significant, at an estimated 3.27 quads/yr, about 37% of the total national pond potential. However, unlike the electric power market, the buildings market is distributed over the country, and concentrated development in a few regions is not possible. Moreover, requirements for space heating is higher in regions with lower insolation, and air conditioning using solar ponds in the high-insolation regions remains to be demonstrated. Techniques for enhancing solar collection in the low-insolation regions, such as tilted reflectors, should be explored. This will be of value particularly to the Atlantic Northeast region where pond potential for building space heating is relatively high.
- (6) Collection enhancement techniques should also benefit the Great Lakes region where the IPH market potential is the highest of any region. The IPH sector possesses over 176,000 existing impoundments whose possible conversion into solar ponds deserves further investigation. Many non-manufacturing industrial processes, such as mining, should

be able to utilize ponds. Also, solar ponds may be practical in providing preheat to some high-temperature industrial processes. These are additional study areas that should be pursued in the future.

- (7) Multipurpose farm ponds offer a number of distinct advantages to the agricultural sector. Initial developmental and commercial effort can concentrate on California, Texas, and the Great Lakes region.
- (8) The desalination market is at present very small. However, the possibility exists that tremendous growth in desalting energy consumption may occur in the next two decades. Solar ponds coupled with distillation desalting plants may offer several advantages. Future development in this area can focus on the Southwest, Salt Lake, and Red River regions.
- (9) Solar pond-desalting plant coupling is but one example of combined technology. Other possible and perhaps promising combinations are solar pond with sewage treatment, solar pond with oil shale development, solar pond with mineral recovery including salt production, solar pond with ethanol production, etc. In most of these combinations, cost benefits can be reaped by both the solar pond and its counterpart. To date, these concepts have received limited attention. Their future development may again reside largely in the high-insolation regions.
- (10) The economic analysis conducted in this study reveals that the major energy cost drivers are the initial capital cost, pond energy output and discount rate. Doubling the capital cost can increase the pond energy cost by 40% to 70%. Doubling the discount rate can increase the pond energy cost by 33% to 102%. But doubling the pond energy output can decrease the energy cost by about 100%. This points out the importance of siting, enhancement of pond performance, reduction of up-front construction cost, and financing arrangement. Creative financing of solar ponds is an issue that has not been specifically addressed and should receive more attention in the future. The impact of reducing construction cost has long been recognized and continued effort should be made to produce low-cost ponds. Enhancing pond performance has been the stated goal of many research programs but few methods have been established to date. Future efforts should be directed toward these three specific areas if the economic viability of ponds is to be improved.
- (11) Speaking of the economic effect of pond performance alone may be misleading. It is actually the performance of the entire pond system that is translated into pond energy economics. Improving the performance of the pond itself is certainly important, but improving the efficiency of the energy distribution subsystem, the power conversion subsystem, and above

all, optimizing the entire system, are also of crucial importance. Solar pond system optimization has barely been addressed, and adequate attention must be paid to the subject.

- (12) For locations that lack certain resources, several R&D items may be important. Evaporation suppressants will aid the water-short regions. Alternate, inexpensive salts will benefit regions with no known salt resources. Enhanced evaporation techniques will improve the likelihood of turning low-saline lakes and coastal regions into solar ponds, and increase the nation's salt resources immensely. Floating ponds will remove the land constraint from many populated coastal cities and make deep existing lakes available for conversion into solar ponds. Research and development efforts addressing these items will preserve or enlarge the nation's pond resources and should not be neglected.
- (13) This regional assessment provides comprehensive, broad information and an overview of the applicability and potential of solar ponds in the United States. The next level of effort should be on a district level and directed toward formulation of master plans. Site-specific studies which must be performed before any pond project can be actually launched are best conducted within the structure of larger scoped, long-term planning and regional development guidelines.