DE-91002163

PROCEEDINGS

SOLTECH 91

- •Solar Industrial Program
- •Solar Thermal Electric Program

Solar Energy Research Institute
Golden, Colorado

SERI

Sandia National Laboratories
Albuquerque, New Mexico

U.S. Department of Energy
Washington, D.C.

VOLUME II

DE91002163 April 1991 CP-250-4254

PROCEEDINGS

SOLTECH 91

- Solar Industrial Program
- Solar Thermal Electric Program

March 25-28, 1991

Solar Energy Research Institute
Golden, Colorado

SERI

Sandia National Laboratories
Albuquerque, New Mexico

U.S. Department of Energy
Washington, D.C.

VOLUME II

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- Symposium Title: Solar Detoxification of Organics in Water
- Date: Wednesday, March 27, 1991 Time: 1:30 p.m. - 5:00 p.m.
- Chairperson(s): Paul Young (NALCO Chemical Company)

Time Slots	Presentations	Proposed Speakers (Name/Affiliation)
1:30 - 1:40	Introduction	Session Chairperson
1:40 - 2:00	Solar Water Detoxification R&D Program Review	John Anderson (SERI)
2:00 - 2:20	Site Considerations for Water Detoxification Project at Lawrence Livermore Laboratory	A.J. Boegel (Lawrence Livermore Laboratory)
2:20 - 2:40	Preliminary Design of a Solar Detoxification Field Experiment	Alan Laxson (SERI)
2:40 - 3:00	Conceptual Design Study for a Solar Detoxification System for the DOE Rocky Flats Facility in Colorado	Bruce Kelly (Bechtel)
3:00 - 3:20	BREAK	

SOLTECH91

Solar Industrial Program/Solar Thermal Electric Program Symposia

- Symposium No: 3 (Concluded)
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- Chairperson(s): Representative from NALCO

Time Slots	Presentations	Proposed Speakers (Name/Affiliation)
3:20 - 3:40	Solar Water Treatment System Concepts and Economics	Hal Link and Craig Turchi (SERI)
3:40 - 4:00	Market Evaluation of Solar Detoxification Technology for Aqueous Waste Streams	Mike Bahm/Richard Osantowski (Radian)
4:00 - 4:20	Recent Results and Implications of Large-Scale Solar Detoxification of Water Experiments	James Pacheco (Sandia)
4:20 - 4:40	Solar Detoxification of Contaminated Water	Ken May and Randy Gee (Industrial Solar Technology)
4:40 - 5:00	Solar Detoxification of Water: Laboratory Research	Dan Blake (SERI)

SOLAR WATER DETOXIFICATION PROGRAM REVIEW

John Anderson

Solar Energy Research Institute

March 27, 1991

3

SOLAR DETOXIFICATION
STRATEGY

- Cultivate productive cooperation between existing solar and waste management industries
- Establish and nurture industrial "champions" of solar detoxification technologies
- Promote market development by working with potential users
- Advance the basic technology to improve costs and expand the accessible market

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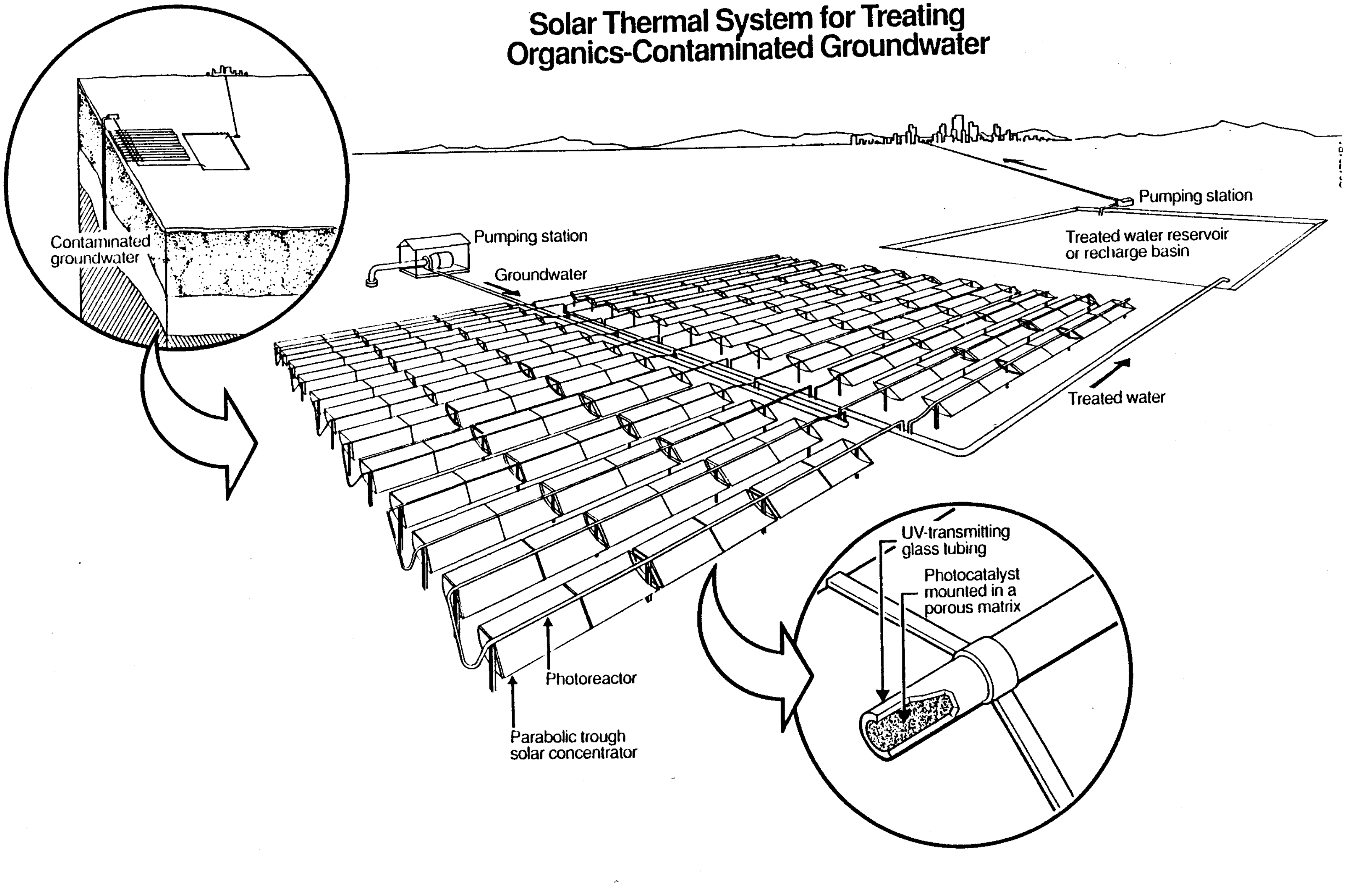
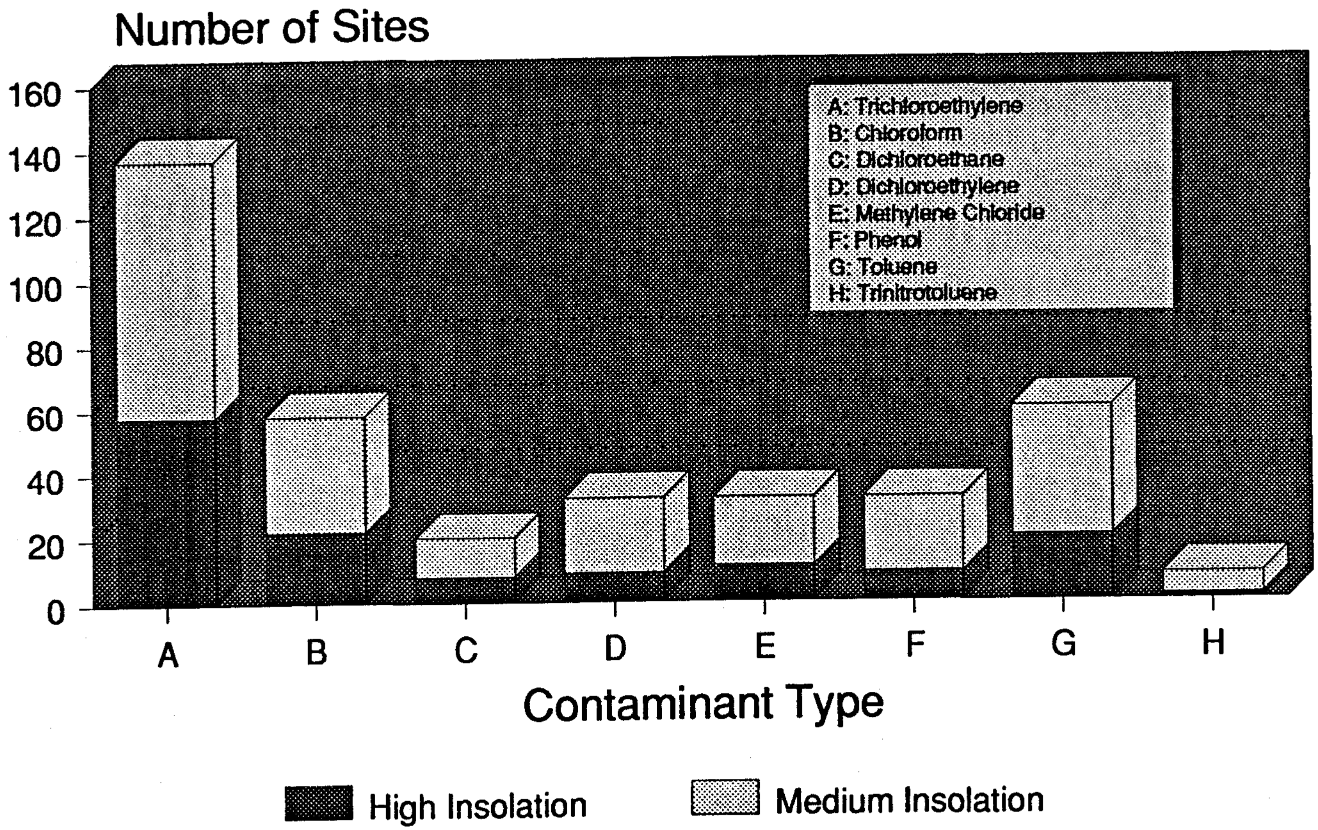
2 SOLAR DETOXIFICATION PROCESSES

Detox of Water	Gas-Phase Detox/ Adsorbed on Solids
Wastewater, groundwater drinking water	Low Btu wastes, soils, used carbon, etc.
Photocatalytic	Photolytic, photocatalytic thermocatalytic
Ambient temperature	High temperature (>700 C)
Low solar fluxes (1 to 30 Suns)	High solar flux (300+ suns)

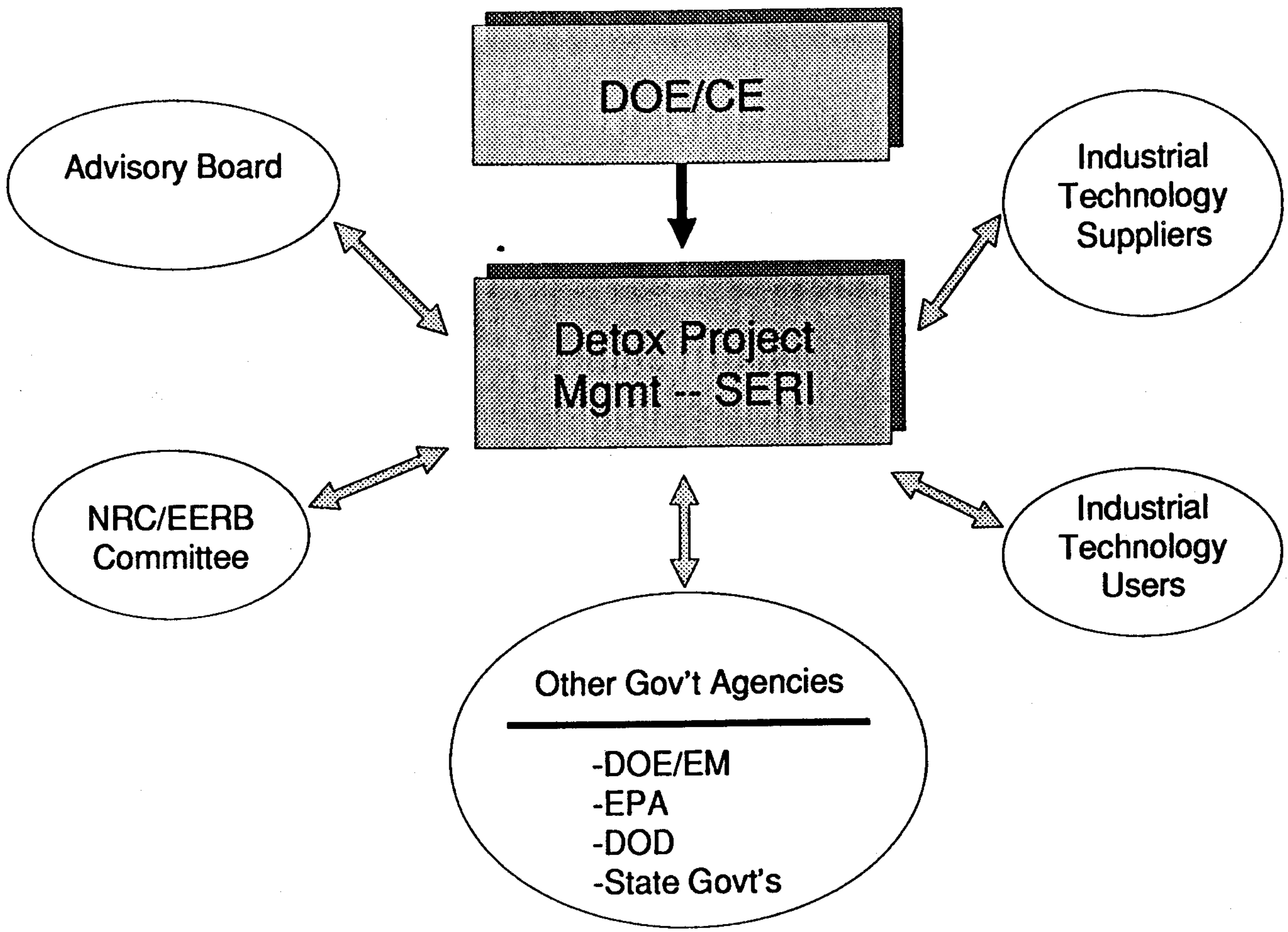
Solar Thermal System for Treating Organics-Contaminated Groundwater



Sites with Potential VOC Contamination
Superfund Sites



SOLAR DETOX PROJECT RELATIONSHIPS



SOLAR DETOX PROJECT

RELATIONSHIP WITH INDUSTRY

- DOE
  Off. Indus. Tech.
  - Project Management
    SERI
    - Research & Development
      - SERI
      - Sandia
      - Universities
    - "Supply"-side Industry
      - Component Development
      - System Development
    - "Demand"-side Industry
      - Treatability
      - Education

INDUSTRIAL TECHNOLOGY DEVELOPMENT

- Focus on companies with long-term commercial interest in the technology

- Innovative concentrator development
  - Review old ideas and new materials
  - Deliver prototypes

- Solar reactor development
  - Criteria: flux distrib, pressure drop, mass transport
  - Deliver prototypes

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INDUSTRIAL "DEMAND-SIDE" ACTIVITIES

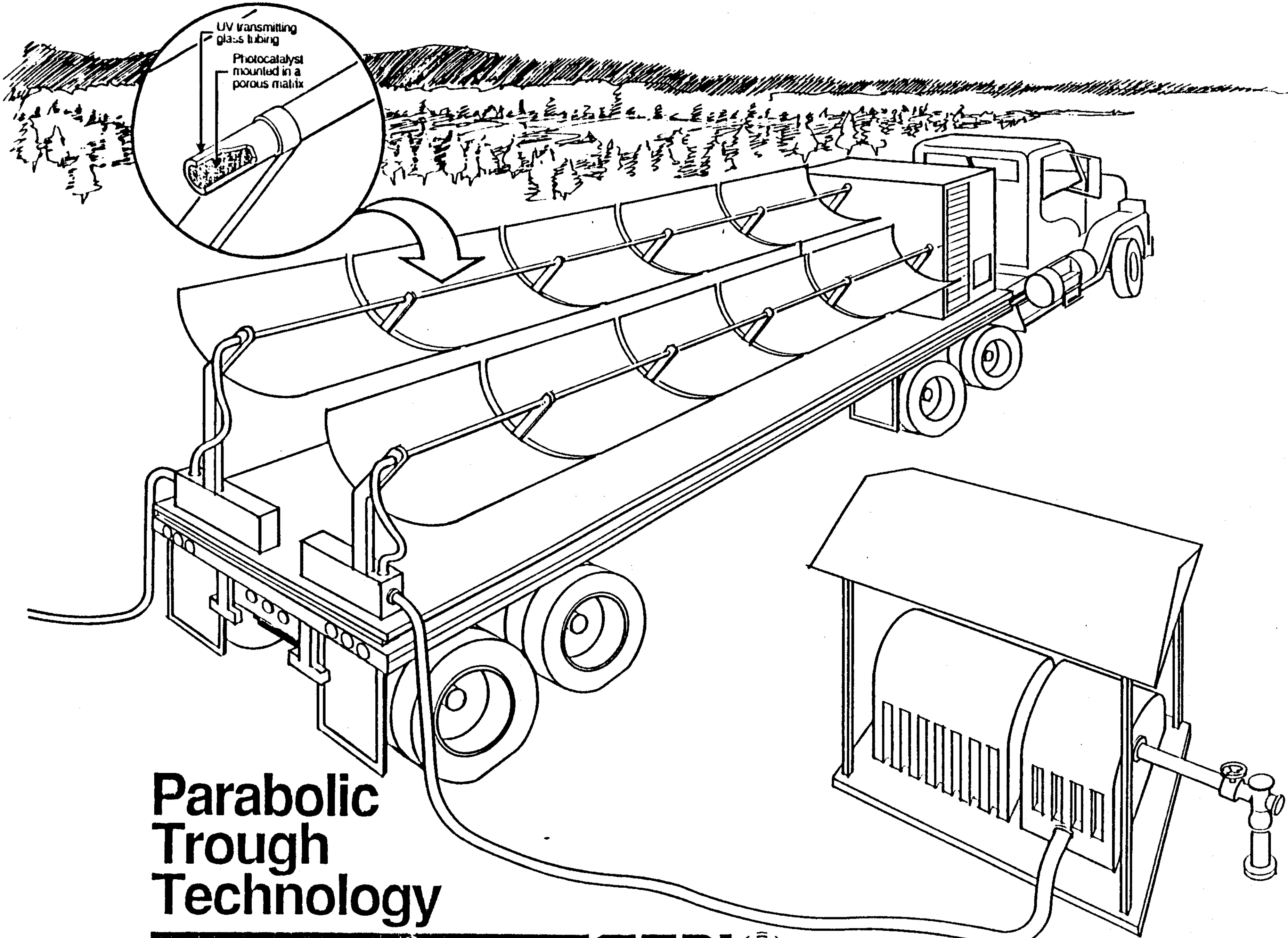
- Companies that want a "finished product" that they can buy and use

- Treatability testing
  - Laboratory tests (underway)
  - Mobile test unit(s)
  - Test and Evaluation Centers

- Other technology transfer activities primarily through organizations like:
  - Air and Waste Management
  - Water Pollution Control Federation
  - ASME, AIChE

- Several treatability contracts in progress

Solar Detoxification of Water



Parabolic
Trough
Technology

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SOLAR DETOX PROJECT

Strategies for "Reaching" Industry

- Direct interactions
- Professional publications/presentations
  - AIChE, ASME, ACS, DOE/DOD/EPA forums
- Media interactions
  - average 1-2 per month
- Responses to information requests
  - approximately 200 in the past year
- Exhibitions at major conferences
  - Air and Waste Management
  - Water Pollution Control Federation
  - AIChE, ASME, etc.

SERI/JVA/PROJ-8C

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SOLAR DETOX PROJECT
MAJOR FEDERAL AGENCY CONTACTS

- DOE/EM
  - co-funding Field Experiment
  - interest from other DOE sites

- EPA
  - Review Board participants
  - funded project with MRI
  - interest from individual site managers

- DOD
  - USATHAMA - Review Board, Pinkwater
  - Army Corps - both solar and environmental experience
  - AFESC - potential groundwater demonstration project
  - NCEL - groundwater remediation

SERI/JVA/FED-1

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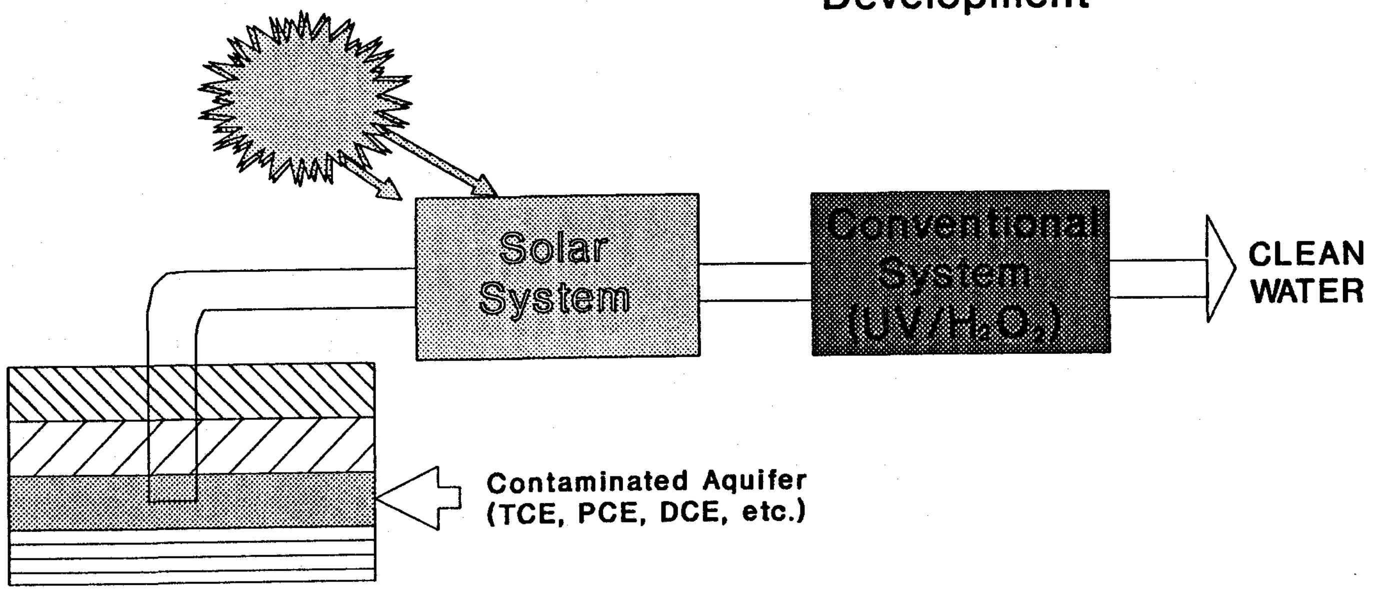
A SOLAR WATER DETOX FIELD EXPERIMENT AT A DOE SITE

A Joint DOE CE/EM Project Managed by SERI
- SERI
- Sandia
- LLNL

- Real World Test
- Establish Operational Procedures and Control Strategies
- Data to Guide Further Development



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SOLAR DETOX OF WATER
TECHNOLOGY CHALLENGES

Issues	Approach
Reactor Design - fixed catalyst - good performance	In-house design (Field Expt) & Indus Reactor Dev (long-term)
Range of treatability	Testing for indus clients & EPA hazard chemical list
Improved performance (primarily catalyst system)	In-house catalyst mat'l work & Univ contracts
Reduced system costs	Indus concentrator development & Univ non-concen. reactor work

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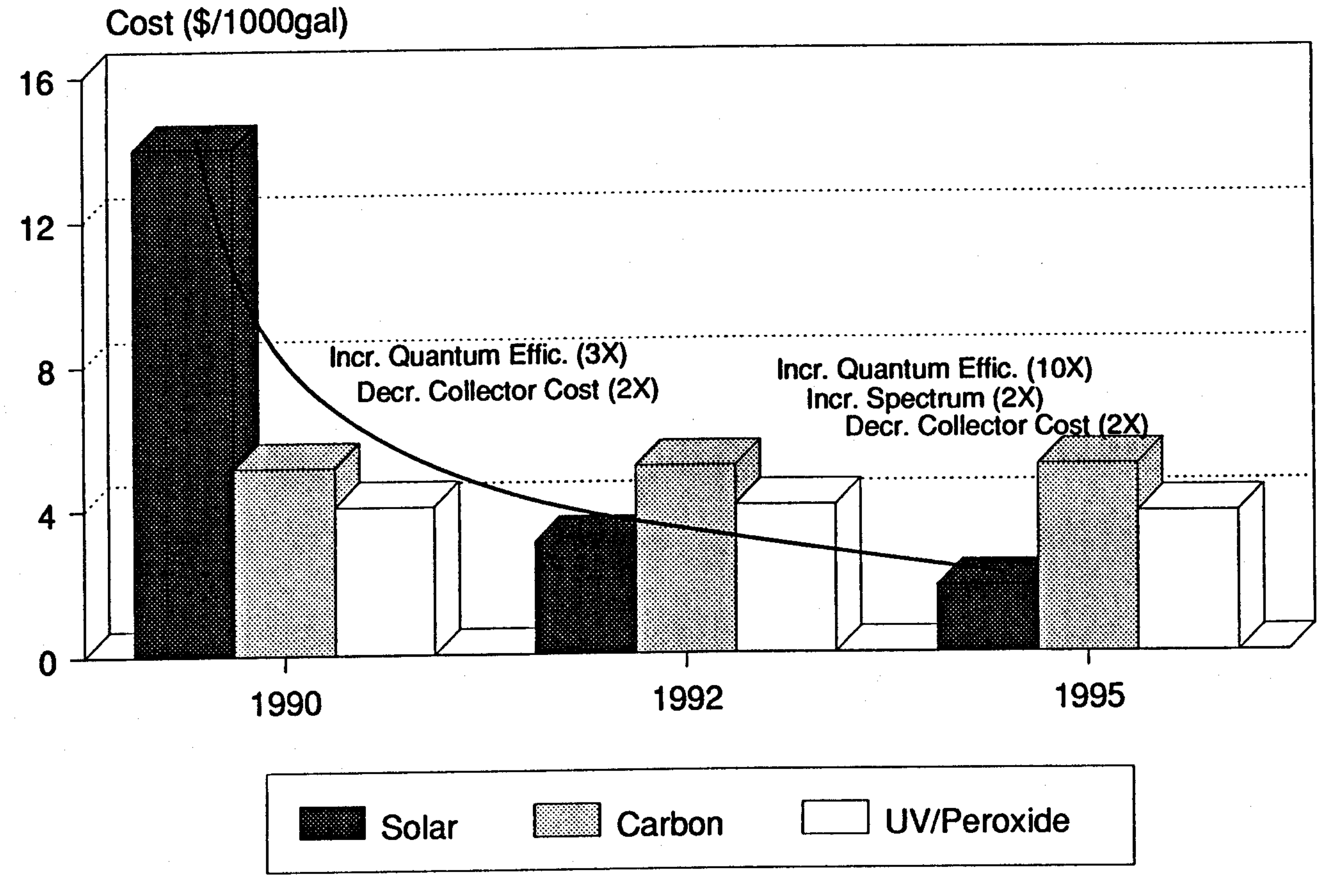
SERI/JVA/CHAL-1

PROJECTED COST OF 0.1 MGD SOLAR DETOX RELATIVE TO COMPETING TECHNOLOGIES



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SERI

Site Considerations for Solar Detoxification Project at LLNL

SOLTECH '91
March 27, 1991
A.J. Boegel
Tim Merrill
Lawrence Livermore National Laboratory

Solar technology for environmental applications has been studied under laboratory conditions by many groups. However, an actual contaminated site has many characteristics that can complicate any cleanup operation and must be adequately addressed before commercialization is possible. These characteristics include the amount and type of contamination, the regulatory requirements, and the effects of other ground water constituents. The laboratory results need to be compared with field results using the same equipment.

The Solar Detoxification Project at LLNL is a collaborative effort by three national laboratories [Solar Energy Research Institute (SERI), Sandia National Laboratory (SNL), and Lawrence Livermore National Laboratory (LLNL)] to take this solar technology out of the laboratory and into the field to detoxify contaminated ground water under actual field conditions. LLNL is the site of this experiment for many reasons. It is a Superfund site already well-characterized. The experiment can be included under existing permits. The existence of permitted LLNL ground water treatment systems makes it possible to perform a technology evaluation of this magnitude. The experimental solar detox facility will be installed in series with an existing permitted treatment facility such that any contaminants remaining in the ground water following detoxification experiments with the solar unit will then be treated by the LLNL facility. LLNL has experience with and has evaluated several related treatment technologies. The project will provide an opportunity for broad experimentation on system variables that will lead to improved system designs and techniques for contaminated ground water remediation.

Site Considerations for Solar Detoxification Project at LLNL

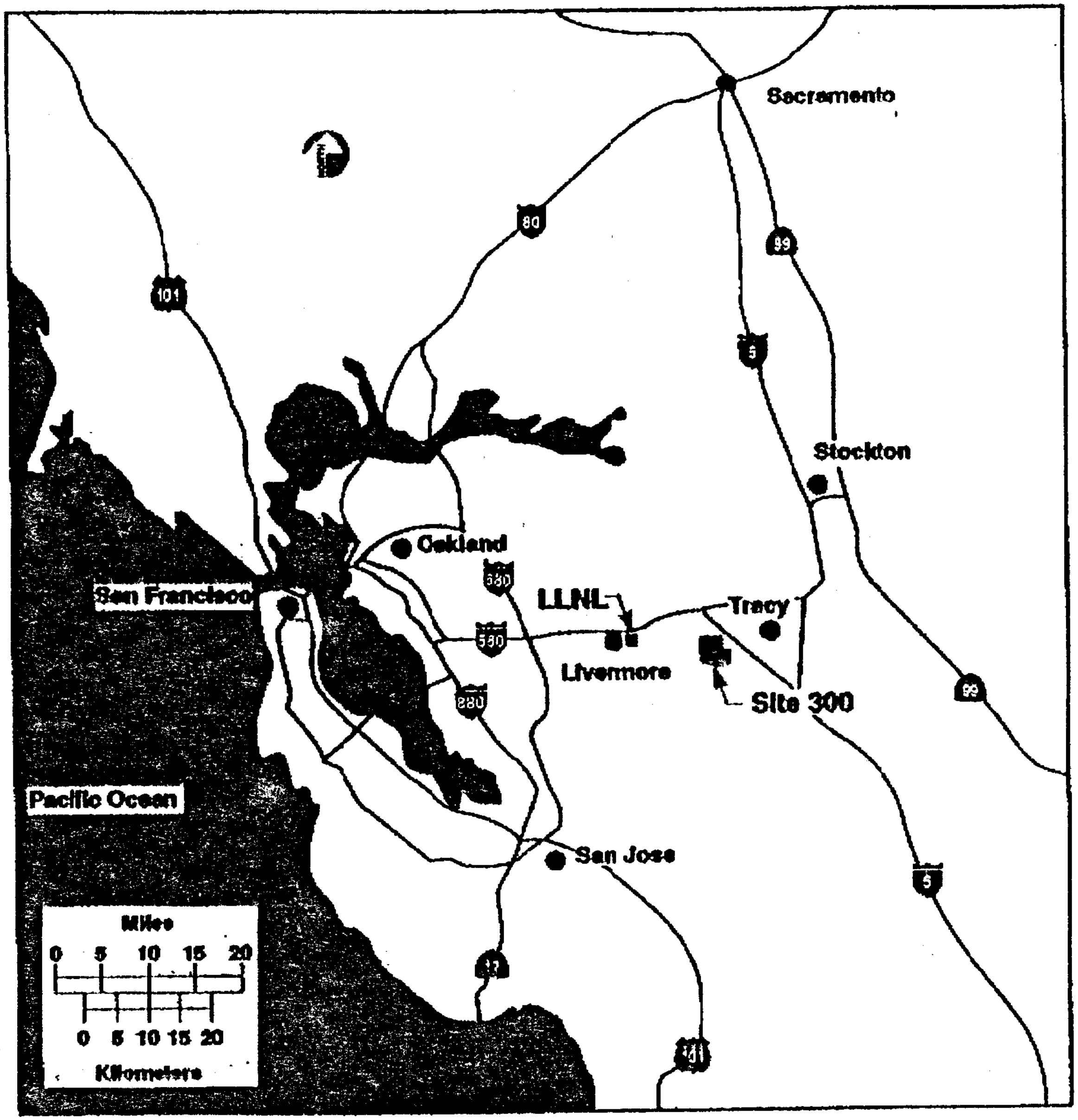
SOLTECH '91
March 27, 1991

A.J. Boegel
Lawrence Livermore National Laboratory

Content

- Location and status
- Regulatory requirements
- Schedule
- Existing treatment system
- Benefits

Locations of LLNL and Site 300



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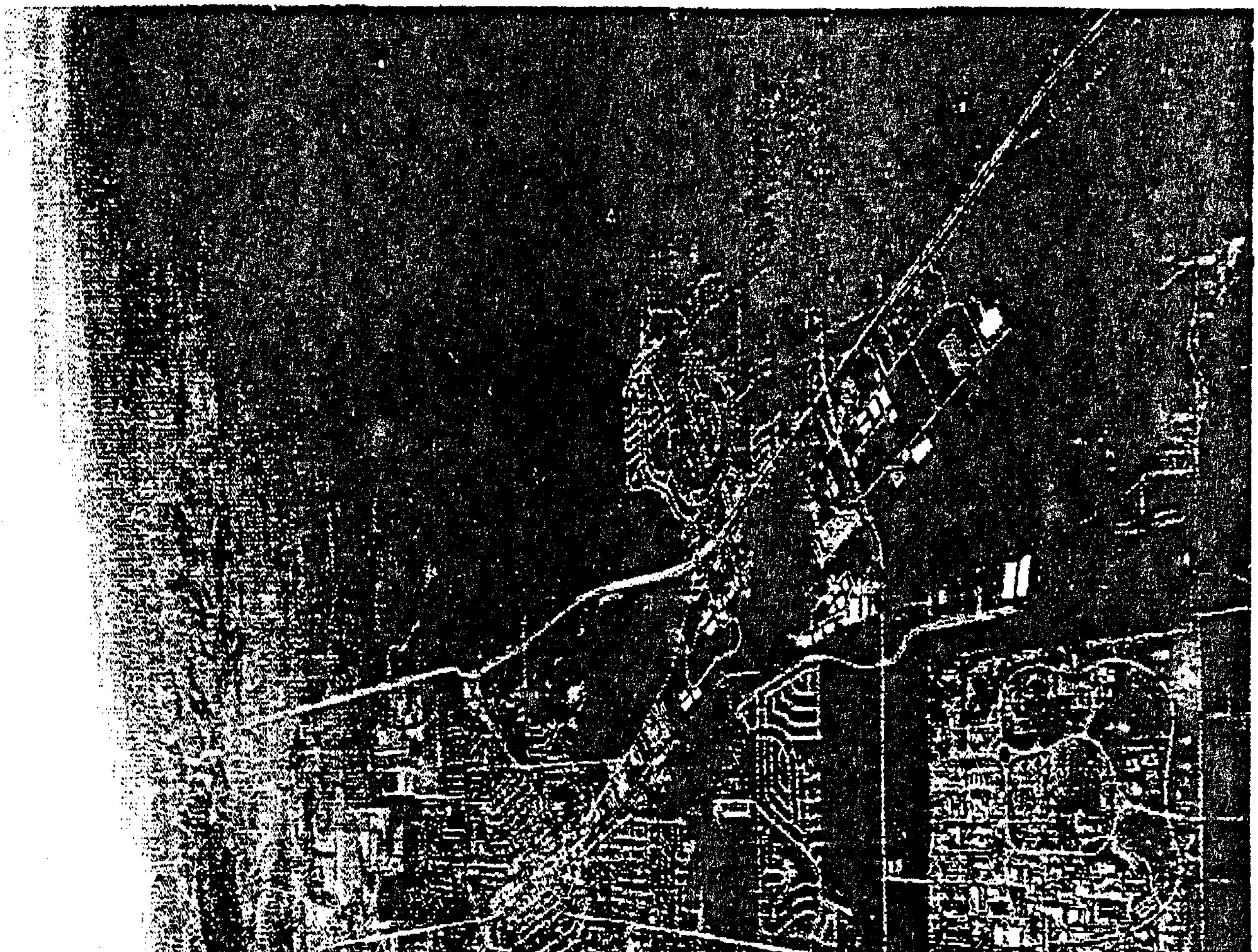
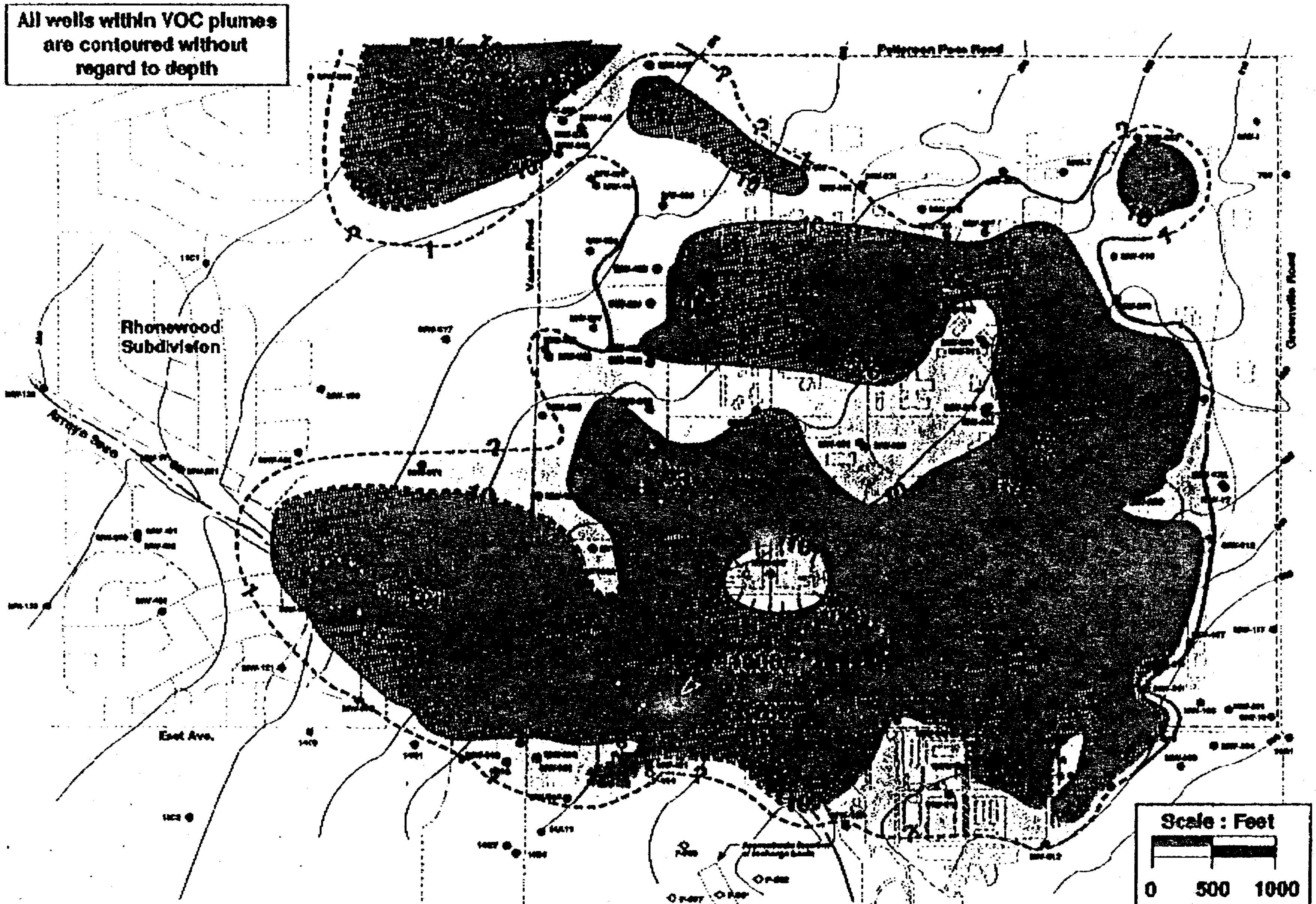
12/10/90



2/28/89

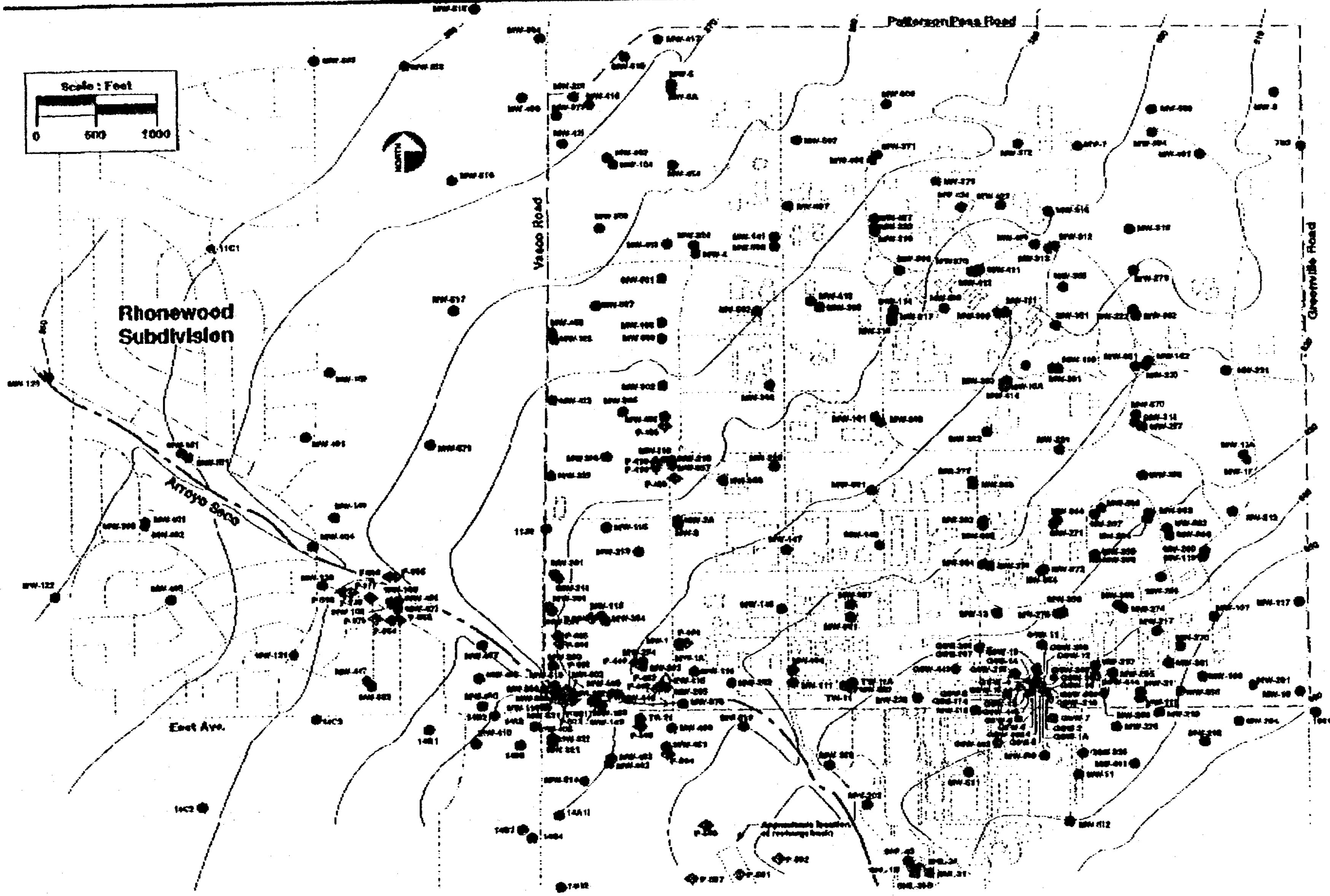
Isoconcentration contour map of total VOCs at LLNL



9/90

Restoration activities

We now have 300 monitor wells

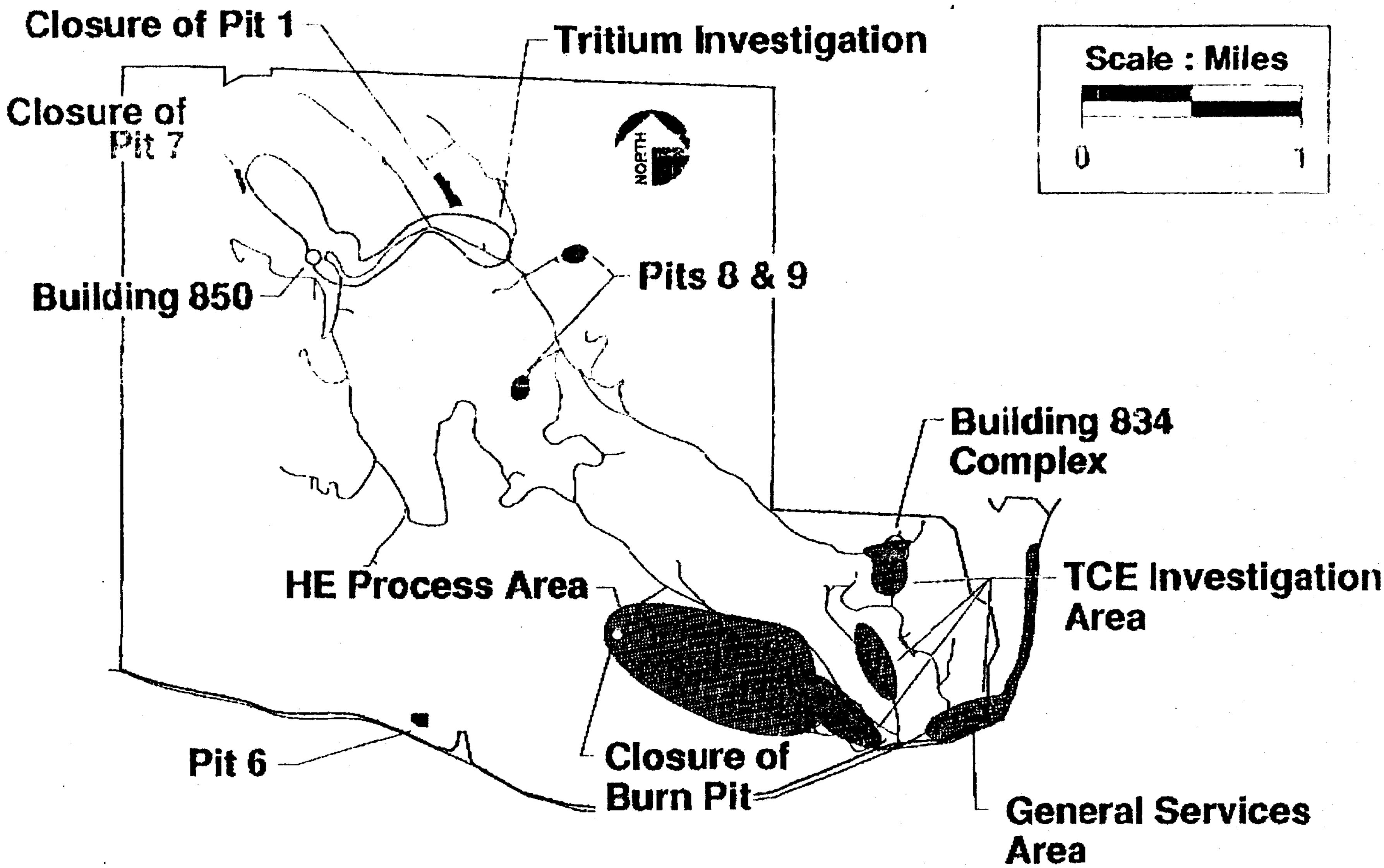


2/12/90

:.5.3.4

Restoration activities

Several environmental restoration activities are in progress at Site 300



3/14/90

26

3.77.13

Regulatory Requirements for Livermore Site

- Federal Facility Agreement (DOE, EPA, and LLNL)
- Main Site and Site 300 on EPA's National Priority List
- California Department of Health Services Compliance Orders
- RWQCB Discharge Requirements
- BAAQMD

Livermore Site Federal Facility Agreement
Timetable for Deliverables

Document	Due Date
RI/FS Work Plan[1]	Draft submitted 10/28/88 Final submitted 5/8/89
Quality Assurance Project Plan[1]	Draft submitted 5/25/88 Final submitted 1/11/89
Community Relations Plan[1]	Draft submitted 10/26/88 Final submitted 5/12/89
Remedial Investigation Report[1]	Draft submitted 12/1/89 Final submitted 3/14/90
Baseline Public Health Assessment[2]	Draft submitted 6/15/89
Feasibility Study Report[1]	Draft submitted 8/1/90 Final submitted 12/17/90

Livermore Site Federal Facility Agreement Timetable for Deliverables (Cont.)

Document	Due Date
Proposed Remedial Action Plan[1]	Draft submitted 2/1/91
Record of Decision[1]	9/1/91
Remedial Action Implementation Plan[1]	10/1/91
Remedial Design[1]	1/1/92
Monthly Reports	Monthly
Annual Reports	Annually

[1] Primary Document
[2] Secondary Document

Projected 1991 Activities at Site 300

Submit:

- FS for the HE Process Area
- FS for Pit 6
- FS for the Building 850/East Firing Area
- RI and FS for Building 833
- Eastern GSA Debris Pile Investigation Report
- Investigation of Holocene Faulting near Pit 6
- RCRA Closure Plan for the HE Burn Pits
- RCRA Closure of Landfill Pits 1 and 7

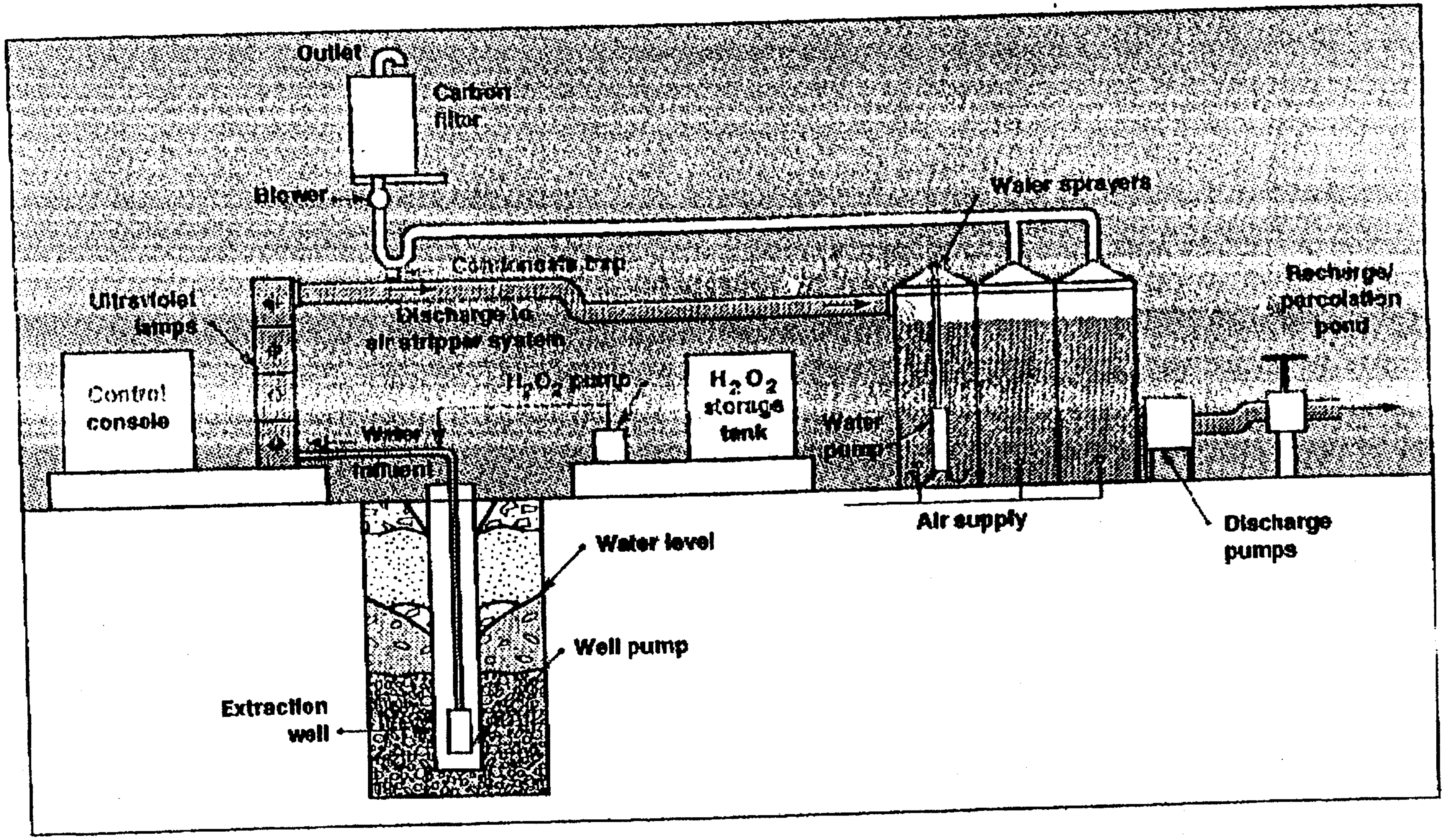
1/25/91-jcz

Projected 1991 Activities at Site 300 (Cont'd).

- Begin remediation of the eastern GSA plume. Conduct pre/post remediation flow net analysis using K-V flowmeter, potentiometric surface mapping, and computer modeling
- Continue pilot testing of innovative remedial technologies at the Building 834 Complex
- Conduct further pilot testing of tritium evaporator
- Prepare overall Site 300 geologic/hydrogeologic assessment report

1/25/91-jcz

UV/H_2O_2 with water-aeration/carbon-absorbtion system



8/13/90

Utilities

Power	— Fast Track Design complete — Installation complete end of May
LCW (Lab cooling water)	— Fast Track Design complete mid-April — Installation complete mid-May
Deionizers	— Source located
Footers and Pads	— Survey — Fast Track Design — Installation complete mid-June

Benefits

- Direct interaction with Technology user
  - Definition of needs/applications
  - Technical experience/judgement
  - Comparison with other technologies
  - Access to remediation sites

- Expand EM experience with attractive new technology
  - Potential use at remote sites with limited power availability
  - Potential cost savings

- Collaborative effort

PRELIMINARY DESIGN OF A SOLAR DETOXIFICATION FIELD EXPERIMENT

Alan S. Laxson
Solar Energy Research Institute, Golden, Colorado

SOLTECH 1991

Photocatalytic destruction of organic compounds in contaminated water driven by solar radiation is being developed into a large-scale field experiment by a consortium of three federal laboratories: the Solar Energy Research Institute, Sandia National Laboratories, and Lawrence Livermore National Laboratory.

The field experiment has four major experimental objectives:

- Advancement of the technology into a nonlaboratory waste remediation environment
- Development of operational procedures
- Compilation of test data to help guide laboratory research and future demonstrations
- Development and testing of plant control strategies.

Plans are to conduct the experiment in two phases. Phase I of the experiment will use skid-mounted equipment and a small solar array to gather data on real groundwater contamination. The equipment skid will be designed so that it is transportable and can be easily upgraded during later phases of the experiment.

Phase II of the experiment will expand on knowledge that has been gained during the first phase. The second phase will expand the facility to utilize advanced solar collectors and will develop information in the areas of advanced control systems, reactor designs, and catalysts. New components used in Phase II will be optimized for the solar detoxification process.

Conceptual design efforts have identified the critical elements of the system. Size and type of solar concentrator, construction materials for balance of plant, operating pressures, flow control, cooling, pretreatment to offset cations and anions are all key elements being optimized to develop a large-scale field experiment. The field experiment will be located at Lawrence Livermore National Laboratory. This Superfund site has groundwater contaminated with approximately 500 ppb of volatile organic compounds, primarily trichloroethylene. Location of the experiment upstream of a commercial UV/Hydrogen Peroxide facility has simplified permitting and toxic release problems since effluent from the solar detoxification experiment will flow through the existing treatment facility before release to the environment. However, it has also added to complexity because of limitations on allowable effluent temperatures and pH. As in the scaling up of any industrial process, the design of a large-scale experiment to test the feasibility of solar-driven photocatalytic detoxification has required resolution of a number of issues not previously identified through research-level investigations.

SOLTECH 91

SOLAR DETOXIFICATION OF WATER FIELD EXPERIMENT

A. LAXSON

MARCH 27, 1991

FIELD EXPERIMENT SIGNIFICANCE

- Critical step in moving detoxification technology from laboratory to commercialization

- Proof of concept in real hazardous waste environment

- Gain necessary field experience to guide next phase of laboratory research and component/system development

WHY LAWRENCE LIVERMORE AS A SITE

- Significant cooperation/interest of LLNL Environmental Restoration Division
- Well characterized hazardous waste stream -- LLNL groundwater
- Ability to operate within existing permitting arrangements
  - LLNL Pilot studies approved with sufficient flexibility to incorporate solar detoxification experiment
  - Verbal endorsement given by regulatory agencies
  - Community supportive of solar experiment

Estimated Masses and Volumes of VOCs in Ground Water

Compound	Mass (lbs)	Percent of Total Class	Volume (gal)
TCE	1300	64	109
PCE	430	21	32
Chloroform	130	6	24
1,1-DCE	100	5	10
Carbon tetrachloride	20	1	2
1,1-DCA	20	1	2
1,2-DCA	20	1	2
1,2-DCE (total)	11	0.5	1
1,1,1-TCA	11	0.5	1
Total VOCs	2042		183

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Chemical Concentrations Measured at Proposed Extraction Wells

VOC	MW-218 (ppb)	MW-357 (ppb)
PCE	1	0
TCE	700	80
1,1-DCE	1	1.5
Carbon tetrachloride	2	4
Chloroform	3	2.5
Freon-113	5	0

Treatment goal--Total VOCs <5ppb

EXPERIMENTAL OBJECTIVES

- Gather field data to guide future laboratory development
- Determine effect of "non-hazardous" groundwater constituents
- Evaluate pre- and post- treatment effects
- Determine catalyst lifetime
- Evaluate sun-following flow-control options

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FIELD EXPERIMENT PLAN

Two-Phased Approach

- First Phase
  - Small array of solar troughs
  - Ancillary equipment skid, shop fabricated and delivered quickly
  - Limited permanent foundations, allows for expansion and change
- Second Phase
  - Retrofit enhanced reactors/receivers/collectors
  - Upgrade or replace ancillary equipment skid

EXPERIMENTAL OBJECTIVES BY PHASES

Gather field data to guide laboratory	Phase I & II
Effects of "non-hazardous" constituents	Phase I & II
Evaluate pre- and post-treatment	Phase I & II
Catalyst lifetime determin.	Phase I & II
Evaluate flow control	Phase II

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EXPERIMENTAL PLANS
(Phase I)

- Groundwater vs. Deionized
- Groundwater Process Conditions
  - Slurry and Fixed Catalyst
    - Light intensity
    - pH
    - Oxidant
    - Velocity
    - Catalyst loading
- Catalyst lifetime
- Other water sources

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EXPERIMENTAL PLANS
(Phase II)

- Innovative collectors
  (Designed specifically for photocatalytic process)

- Innovative receivers/reactors

- Improved fixed catalyst and/or slurry filtration systems

- Evaluate flow control

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LAWRENCE LIVERMORE DESIGN CONSIDERATIONS AND RESTRICTIONS

- California Regional Quality Control Board
  - Effluent temperature limit
  - Effluent pH
- California State Air Emissions Standards
- Seismic Zone
- Limited available site utilities
- Must operate without impacting existing treatment facilities.

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NEED FOR PRE- AND POST-TREATMENT

- Effect of Carbonates
- Effect of Metal Ions
- pH Effect

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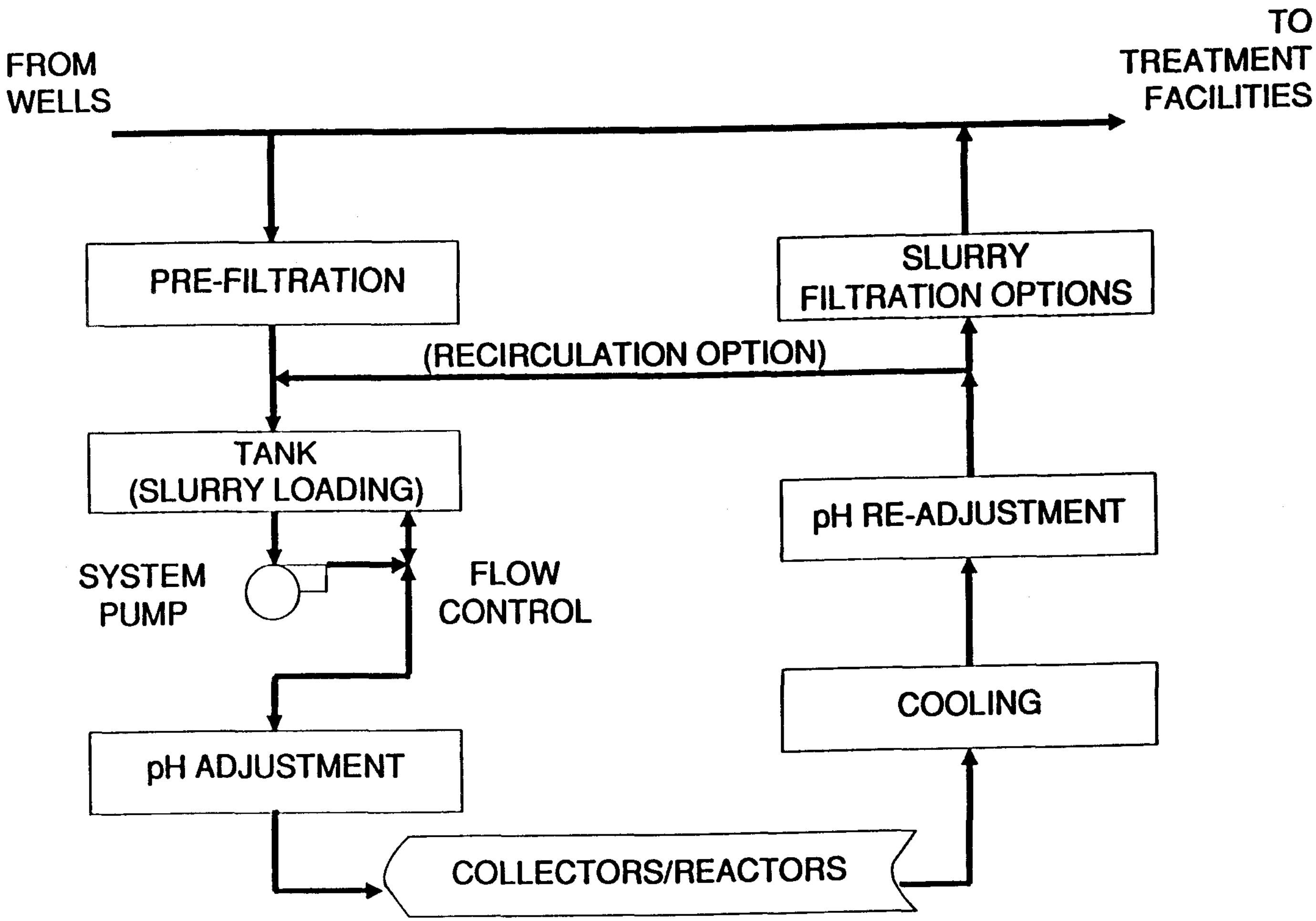
FIELD EXPERIMENT FLOW DIAGRAM



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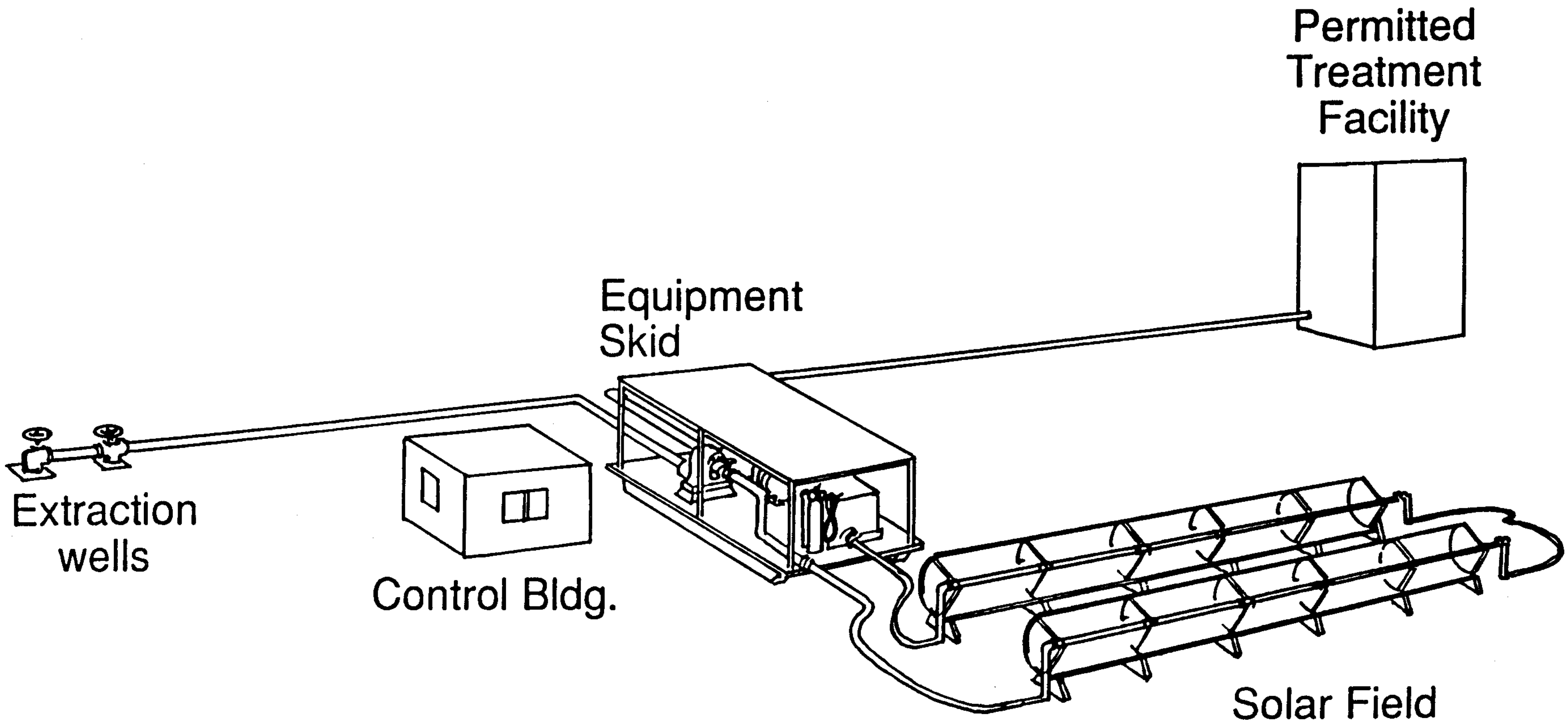
DESIGN CONCEPTS

- Inlet Prefiltering
- Surge Tank (Slurry Loading)
- Flow Control
- pH Adjustment
- Collector/Reactor
- Cooling
- pH Readjustment
- Recirculation Option
- Slurry Filtration



Field Experiment
(Artists Concept)

ABSTRACT

CONCEPTUAL DESIGN STUDY FOR A SOLAR DETOXIFICATION SYSTEM FOR THE DOE ROCKY FLATS FACILITY IN COLORADO

Bruce Kelly

Sandia National Laboratories, in cooperation with the Solar Energy Research Institute (SERI), have contracted with Bechtel Corporation for the conceptual design and permitting plan of a demonstration solar detoxification project. The objectives of the study are to assess the following:

- The cost and schedule of a demonstration program for DOE planning purposes
- The economic potential of future commercial facilities.

The site selected for the study is the Rocky Flats Plant in Colorado, and the design groundwater flow rate is 0.0063 m^3/sec (100 gpm).

A pretreatment system modifies the groundwater chemistry in three areas to ensure complete decomposition of the toxic compounds. The first two requirements, as specified by SERI, include adjustment of the pH to a nominal value of 6 and addition of hydrogen peroxide (H_2O_2) and oxygen (O_2). The third requirement is the decomposition of calcium bicarbonate ($Ca(HCO_3)_2$) to prevent scale formation on the catalyst.

The facility requires 1,145 m^2 (12,320 ft^2) of parabolic trough solar collectors to reflect the required ultraviolet flux on the receiver tubes. With a collector width of 2.1 m (7 ft) and a receiver tube diameter of 50 mm (2 in.), the concentration ratio at the outside of the tube is 42:1. The catalyst is impregnated in a fiberglass cloth, which is rolled into the shape of a tube, and inserted into the borosilicate glass receiver tube. The collectors use an aluminum reflector to provide a high reflectivity in the ultraviolet portion of the spectrum.

A posttreatment system modifies the treated water chemistry to meet Federal and Colorado regulatory requirements for discharge into a surface water. The modifications include:

- Reduction in the total dissolved solid concentrations to meet drinking water standards
- Increase in the pH to a nominal value of 6 to 9.

Assuming the facility operates for 7 days per week and 52 weeks per year, the annual volume of water treated by the facility is estimated to be 8,500,000 gallons.

To construct the facility, the following principal permits must be obtained:

- National Pollutant Discharge Elimination System (NPDES) (Federal)
- Resource Conservation and Recovery Act/Land Ban (RCRA) (Colorado)
- Hazardous Waste Transportation, Storage, and Disposal Site and Facility (TSD) (Colorado)
- Well Drilling and Building Permits (Colorado).

An economic summary of the facility, in constant year 1991 dollars and excluding escalation, shows the following:

- $1,720,000 capital cost
- $124,000 annual operation and maintenance cost
- 12.7 percent levelized capital carrying charge
- Treated water cost of $40.40/1000 gallons, of which $25.80 is due to annual capital expenses and $14.60 is due to annual operating expenses

This treated water cost is several times that from commercial water treatment facilities using air stripping or ultraviolet lamps. However, much of the capital and operating cost in the solar facility is due to regulations that require the total dissolved solid concentrations in the discharge water to meet drinking water standards. If a recharge basin can be identified that does not demand as strict a standard, the cost of water from the solar facility will decrease considerably. Other changes which will reduce the cost of treated water include:

- Selection of a collector field which is larger than that required to meet the design point flow rate. Although this will increase the capital cost, the capacity factor of the pretreatment and posttreatment equipment will increase, and the overall facility economics will improve
- Reinstitution of Federal or state solar investment tax credits, which will decrease the levelized capital carrying charge
- Research in catalysts which can use a larger portion of the ultraviolet spectrum and development of low cost collectors. Both activities are underway as part of the DOE Solar Thermal Program.

CONCEPTUAL DESIGN STUDY FOR A SOLAR WATER DETOXIFICATION SYSTEM FOR THE DOE ROCKY FLATS FACILITY IN COLORADO

BRUCE KELLY

BECHTEL CORPORATION
SAN FRANCISCO, CALIFORNIA

DESIGN BASIS

- STANDALONE FACILITY TREATING GROUNDWATER CONTAMINATED WITH CHLORINATED HYDROCHARBONS

- 5×10^{22} ULTRAVIOLET PHOTONS (280 - 380 MICRON) PER SECOND TO OUTSIDE OF 2 INCH DIAMETER RECEIVER TUBE

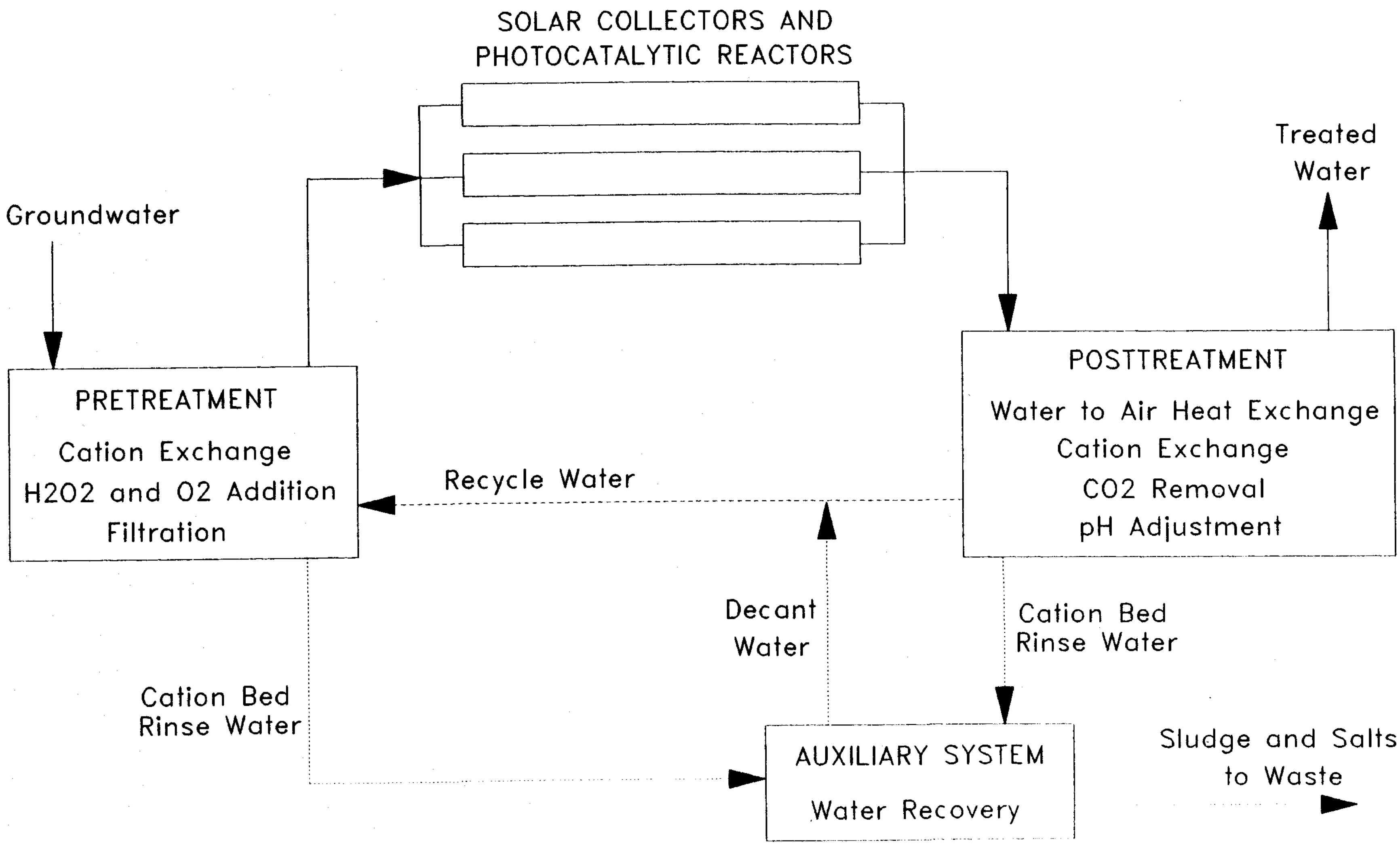
- CLEAR VERNAL EQUINOX NOON

- 100 GPM TREATED WATER FLOW RATE

- GROUNDWATER pH = 7.6
  RECEIVER INLET AND FACILITY OUTLET pH = 6

- GROUNDWATER TOTAL DISOLVED SOLIDS = 818 PPM
  FACILITY OUTLET TDS = 400 PPM (DRINKING WATER QUALITY, SUITABLE FOR DISCHARGE TO SURFACE WATERS)

SIMPLIFIED FLOW DIAGRAM



PRETREATMENT SYSTEM

- CATION BED EXCHANGER
  - HYDROGEN IONS EXCHANGED FOR CALCIUM IONS
  - REDUCES pH
  - REDUCES TDS CONCENTRATION
  - REMOVES CALCIUM BICARBONATE: PREVENTS SCALE FORMATION DUE TO THERMAL DECOMPOSITION AND REDUCES COMPETITION FOR HYDROXYL RADICALS
- HYDROGEN PEROXIDE AND OXYGEN ADDED AS HOLE RECEPTORS FOR GENERATION OF HYDROXYL RADICALS
- 5 MICRON FILTER REMOVES IRON OXIDES

COLLECTOR SYSTEM

- ALUMINUM REFLECTOR FOR HIGH UV REFLECTIVITY
- SOLAR KINETICS TROUGH SELECTED FROM VENDOR SURVEY
- 1,145 M^2 REQUIRED
- 11 ROWS WITH 8 TROUGHS PER ROW
- SLOPED SUPPLY AND RETURN HEADERS FOR AUTOMATIC DRAINING ON SHUTDOWN
- RECEIVER: 2 INCH DIAMETER BOROSILICATE GLASS WITH TITANIUM DIOXIDE CATALYST IMPREGNATED IN A FIBERGLASS CLOTH

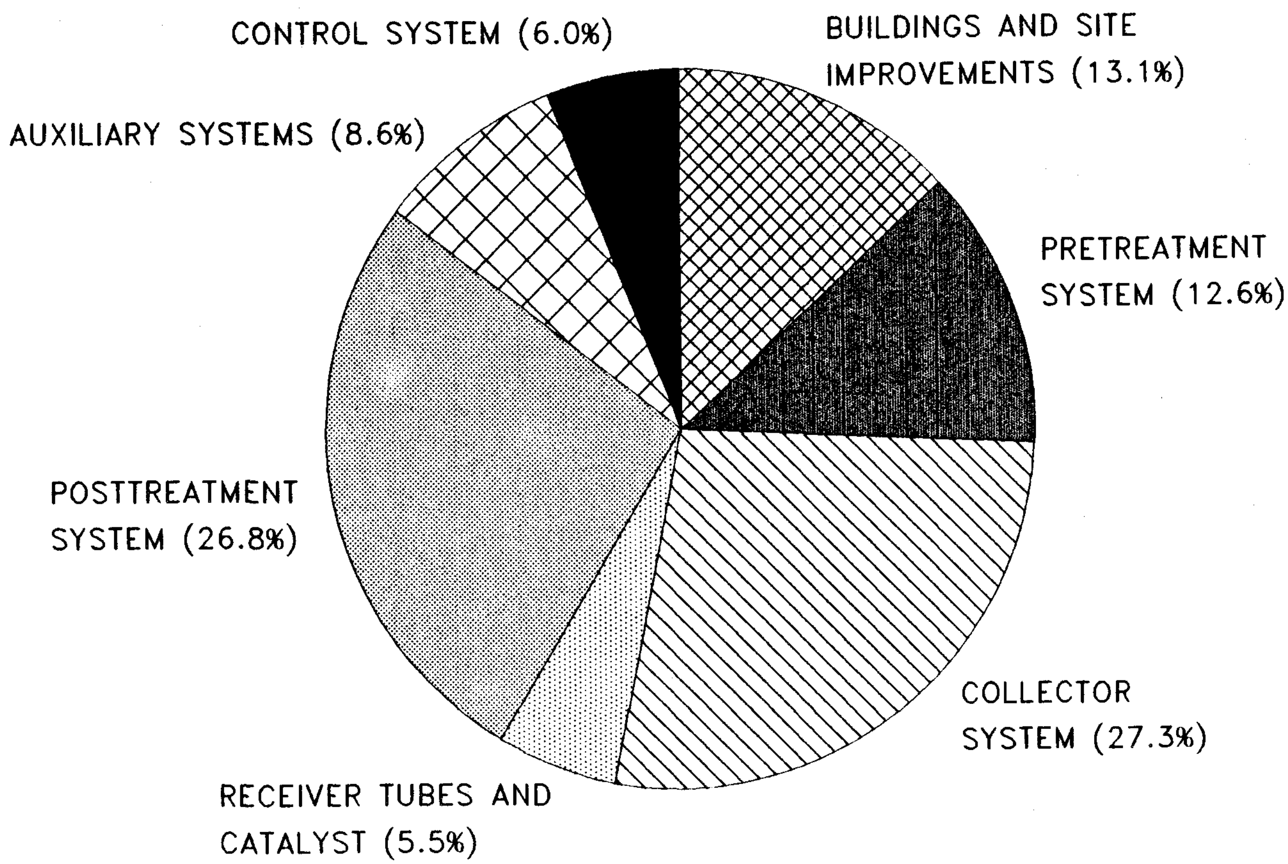
POSTTREATMENT SYSTEM

- WATER TO AIR HEAT EXCHANGER
- FERRIC CHLORIDE CATALYST DECOMPOSES RESIDUAL HYDROGEN PEROXIDE
- CATION BED EXCHANGER REDUCES TOTAL DISSOLVED SOLIDS TO 400 PPM
- AIR BLOWN DEGASIFIER REDUCES DISSOLVED CARBON DIOXIDE CONCENTRATION AND INCREASES pH
- SODIUM HYDROXIDE ADDITION INCREASES pH to 6

ANNUAL PERFORMANCE

Minimum Flow, GPM	Operating Months	Treated Water Volume, 1000 Gal	Capacity Factor
0	12	8,900	0.170
20	12	8,500	0.161
20	9	7,300	0.140

DISTRIBUTION OF TOTAL FIELD COST



ECONOMIC ANALYSIS

- CONSTANT YEAR (1991) DOLLARS; ESCALATION EXCLUDED

- $1,720,000 CAPITAL COST

- $124,000 ANNUAL OPERATION AND MAINTENANCE COST

- PRIVATE FINANCING AND OWNERSHIP; 0.127 LEVELIZED CAPITAL CARRYING CHARGE

- TREATED WATER COST

- CAPITAL COST	$25.80/1000 GALLONS
- O&M COST	$14.60/1000 GALLONS
TOTAL	$40.40/1000 GALLONS

CONCLUSIONS

STANDALONE FACILITY PRODUCING DRINKING QUALITY WATER IS NOT ECONOMIC

- SIGNIFICANT PRE- AND POSTTREATMENT CAPITAL AND OPERATING COSTS
- LOW CAPACITY FACTORS

NEED TO IDENTIFY A LESS COMPLEX WATER TREATMENT PROBLEM

POTENTIAL IMPROVEMENTS

- SELECT A RECHARGE BASIN THAT DOES NOT REQUIRE DRINKING QUALITY WATER
  - PUBLICLY OWNED WATER TREATMENT WORK
  - RECYCLE AS PROCESS WATER TO INDUSTRIAL FACILITY
- INCREASE COLLECTOR AREA AND IMPROVE CAPACITY FACTOR OF PRETREATMENT AND POSTTREATMENT SYSTEMS
- CONTINUE RESEARCH IN CATALYSTS WHICH USE A LARGER PORTION OF UV SPECTRUM OR REQUIRE A MINIMUM OF GROUNDWATER PRETREATMENT

SOLAR WATER TREATMENT SYSTEM CONCEPTS AND ECONOMICS

Hal Link and Craig S. Turchi
Solar Energy Research Institute
Golden, Colorado

Laboratory and small-scale field experiments have shown that concentrated solar flux can be used to detoxify water contaminated with a variety of hazardous chemicals [1,2,3]. By directing the ultraviolet portion of sunlight onto a catalyst immersed in contaminated water, solar detoxification systems break down toxic organic chemicals into nontoxic compounds such as carbon dioxide (CO_2), water (H_2O), and dilute hydrochloric acid (HCl). Additionally, solar water detoxification contains environmental benefits compared to other treatment technologies, notably low power consumption and on-site contaminant destruction. The Solar Energy Research Institute (SERI) and Sandia National Laboratories are heading the U.S. Department of Energy efforts to develop solar detoxification technology for commercial application.

Solar Water Detoxification. The solar water detoxification system uses photocatalytic chemistry involving a complex series of reactions [4,5,6]. In the current configuration, a parabolic-trough concentrator focuses sunlight on a clear glass tube used as the receiver. Inside this photoreactor, the near-ultraviolet portion of the solar spectrum activates a catalyst in a process that produces hydroxyl radicals. Given sufficient exposure to hydroxyl radicals, organic pollutants break into nontoxic materials such as CO_2 and H_2O. In the case of the commonly found chlorinated solvents, dilute HCl is also formed.

Representative Site for Solar Water Detoxification. Initial investigations have identified three potential markets for solar water detoxification: remediation of contaminated groundwater, treatment of industrial wastewater, and purification of drinking water. Within these broad markets, SERI projections have shown the first commercial solar plants are likely to be characterized by appropriate contaminant type (e.g., difficult to adsorb or air-strip but easily oxidized), dilute contaminant concentration, small treatment capacity, and sunny location.

The case presented here is for a site known as Treatment Facility B at Lawrence Livermore National Laboratory in northern California [7]. This site is typical for groundwater remediation, i.e., pump contaminated water to the surface, treat, and reinject into the aquifer. The facility will treat an average flow of 3.5 L/s (55 gpm) on a 24 h/day basis. Because of the varying nature of solar radiation, actual flows through the solar system would vary between 0 and 24 L/s (375 gpm). The water at Treatment Facility B is contaminated with a variety of organic chemicals, the most prevalent being trichloroethylene (TCE), a chlorinated organic solvent frequently found in contaminated groundwater. The Livermore site has good solar resources and is typical for most of the western one-third of the contiguous United States.

Cost Analysis. Few cost studies have been attempted for photocatalytic water treatment [8,9]. In addition, because there are as yet no full-scale systems, these projections are based on laboratory and limited outdoor tests. The approach taken in this analysis is to determine kinetic parameters from tests conducted under conditions as close as possible to those of the representative system. A computer model uses these parameters to project what flow can be treated under the conditions of the full-scale system.

Each change between the test conditions and the field conditions results in a increased level of uncertainty in performance. Two key assumptions are made in the extrapolation of available data to projected field system performance: (1) that fixing the catalyst on a support will not decrease its performance from that of slurries and (2) that destruction rates for TCE in groundwater will be similar to those obtained in field tests using pure TCE in clean water.

Capital costs were converted to an annual cost using a fixed charge rate (FCR) of 0.134. The treatment cost was calculated as

$$\text{Treatment Cost (\$/1000 gal)} = (\text{Capital*FCR} + \text{O\&M})/(\text{Treatment Capacity}).$$

Using this analysis the current solar system cost was estimated at $16/1000 gallons. A similar analysis was performed for a granular activated carbon (GAC) system and a lamp-driven hydrogen peroxide oxidation process. Costs for these systems were estimated at $4-$5/1000 gallons based on information from investigators at Lawrence Livermore National Laboratory [7]. Even though competitive treatment systems are more expensive in this size range than some advertised figures may indicate, solar systems at $16/1000 gallons cannot compete for this application. However, since the solar technology is not ready for commercial application, it is more reasonable to compare costs when uncertainties have been reduced and performance has been improved.

Improvements to Solar Water Detoxification System. Although present treatment costs for the solar water detoxification system are higher than for conventional technologies, the potential exists for significant cost reductions and performance improvements in several areas. These areas and the expected levels of improvement based on current laboratory findings are

- increasing performance by improving catalyst efficiency (3X),
- increasing the usable portion of the solar spectrum (potential 2X),
- increasing performance by adjusting process conditions (2X), and
- reducing system costs by reducing collector and/or reactor cost (2X).

A combination of field experiments and in-house and subcontracted laboratory activities should lead to significant improvements in these areas within the next two to three years. By transferring process improvements demonstrated in laboratory experiments to field systems, a solar water treatment system that is cost-competitive with conventional carbon treatment and lamp-driven advanced-oxidation systems could be available for demonstration by the mid-1990s.

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[4] Peterson, M. W., J. A. Turner, and A. J. Nozik, *J. Phys. Chem.*, **95**, 221 (1991).

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[6] Serpone, N. and E. Pelizzetti, Eds., Photocatalysis: Fundamentals and Applications, Wiley, New York, 1989.

[7] Isherwood, W. F., C. H. Hall, and M. D. Dresen, "CERCLA Feasibility Study for the LLNL-Livermore Site," UCRL-AR-104040, July 1990, Lawrence Livermore National Laboratory, Livermore, CA. (Draft Report)

[8] Ollis, D. F., "Process Economics for Water Purification: A Comparative Assessment," in Photocatalysis and Environment, M. Schiavello, Ed., Kluwer Academic Pub., Dordrecht, 1987.

[9] Link, H. F. and C. S. Turchi, "Cost and Performance Projections for Solar Water Detoxification Systems," presented at: ASME International Solar Energy Meeting, Reno, Nevada, March 17-22, 1991.

SOLAR WATER TREATMENT SYSTEM CONCEPTS AND ECONOMICS

Presented at
SOLTECH91
March 27, 1991 - Burlingame, CA

Hal Link and Craig S. Turchi
Solar Energy Research Institute
Golden, Colorado

OUTLINE

- Representative Treatment Site
- Solar and Competing Technology Costs
- Solar Process Improvements
- Conclusions

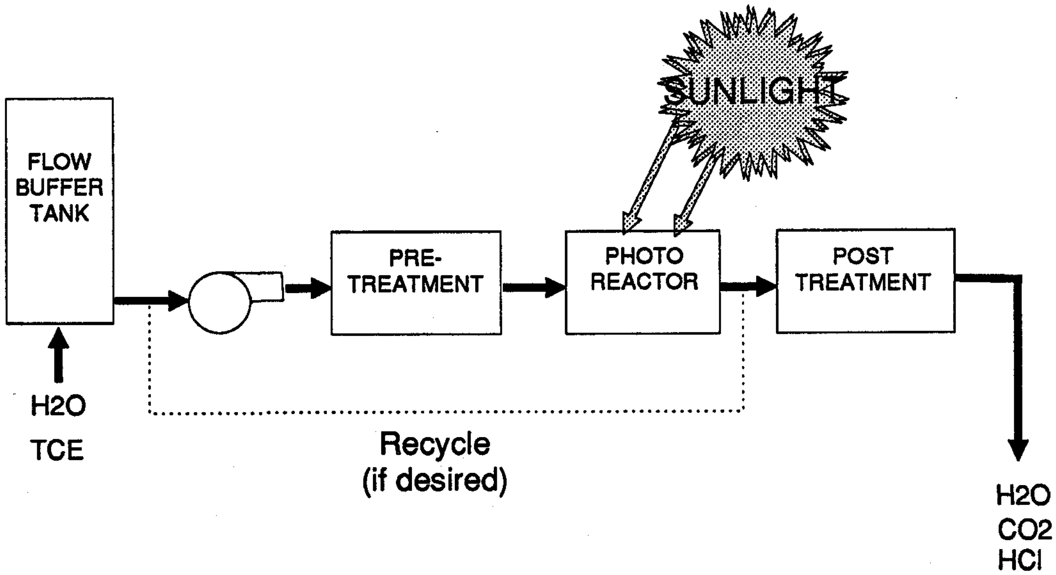
REPRESENTATIVE PLANT CHARACTERISTICS

- Lawrence Livermore National Laboratory site
- 100,000 gallons groundwater per day
- 400 ppb trichloroethylene (TCE) inlet
- Discharge level < 5 ppb TCE

COMPETING TECHNOLOGIES

- Granular Activated Carbon
- UV-lamp/Hydrogen Peroxide
- Solar Detoxification

SOLAR WATER DETOXIFICATION
REPRESENTATIVE SYSTEM CONFIGURATION



SERI

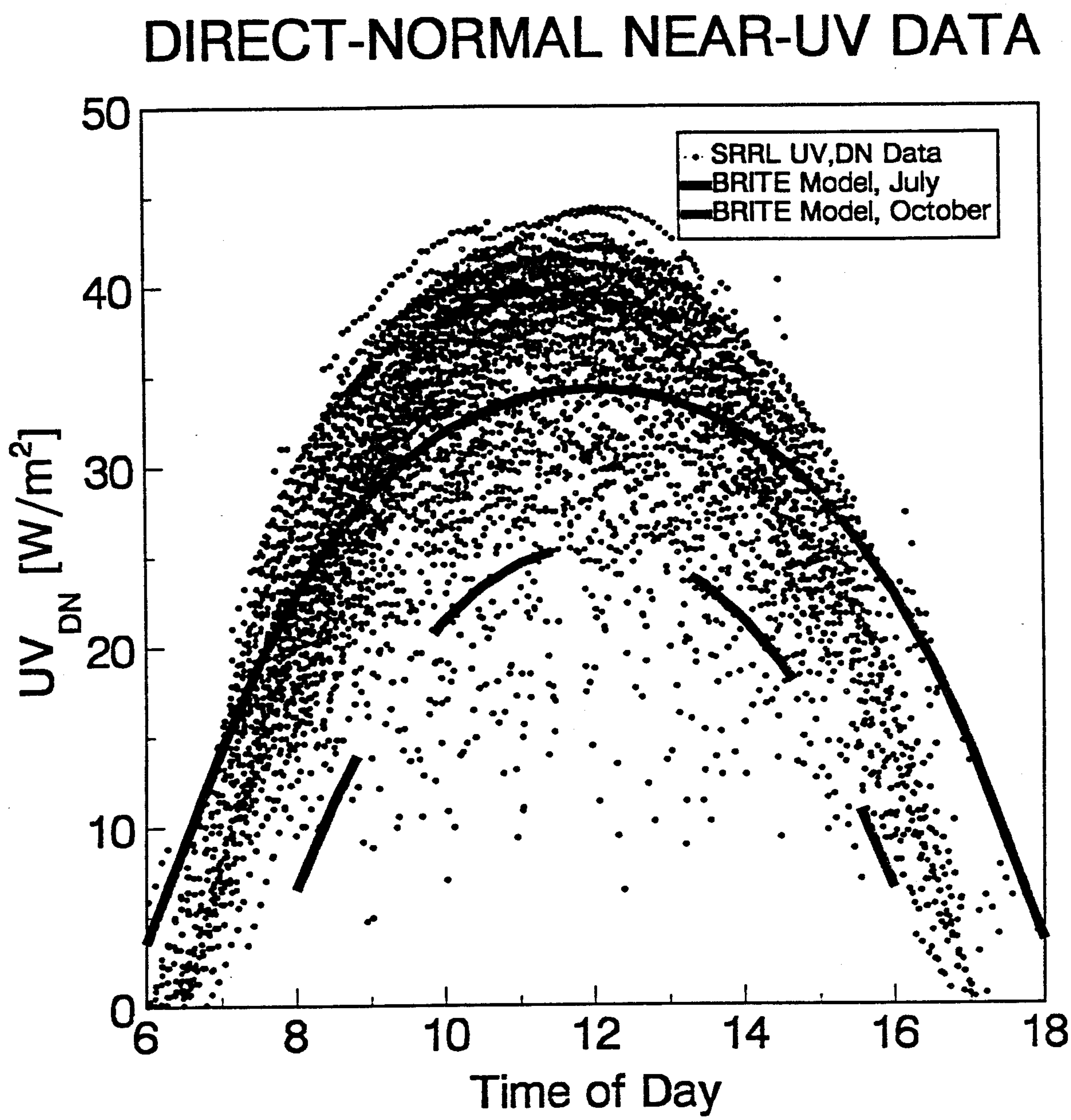
SOLTECH91

SOLAR PERFORMANCE ANALYSIS BASIS

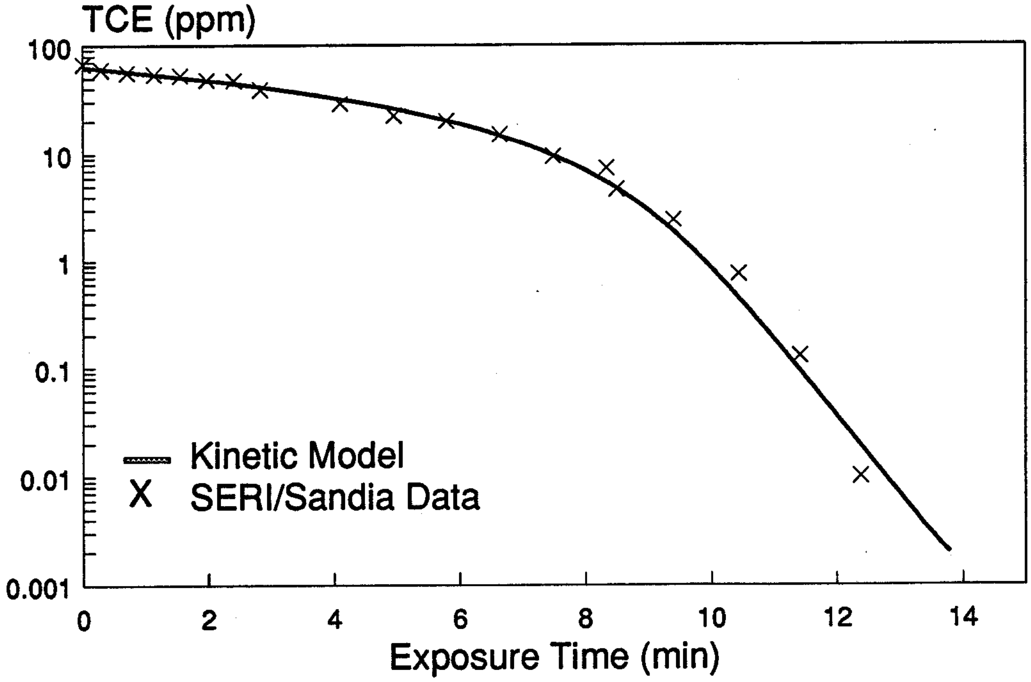
- Kinetics based on SERI & Sandia trough experiments
- Ultraviolet resource predicted by model
- Fixed catalyst equivalent to slurry
- Non-hazardous groundwater component effects negligible

SERI

SOLTECH91

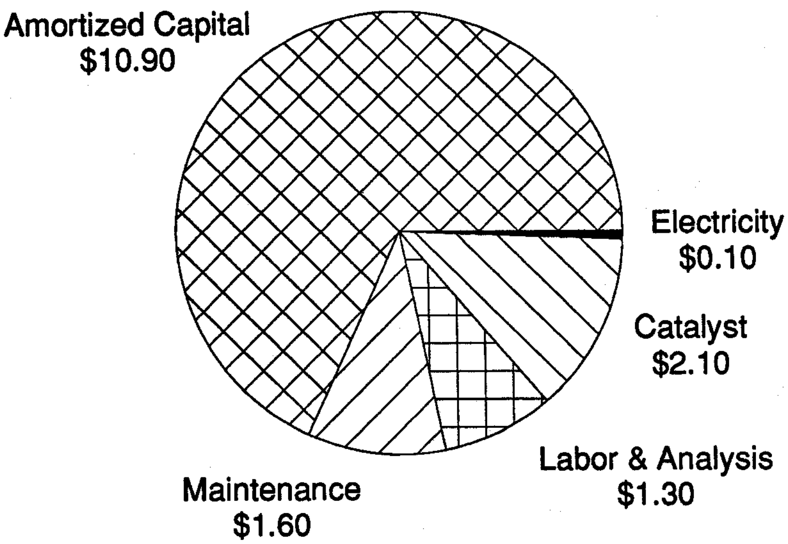

DIRECT-NORMAL NEAR-UV DATA
SRRL UV,DN Data
BRITE Model, July
BRITE Model, October
UV_{DN} [W/m^2]
0
10
20
30
40
50
6
8
10
12
14
16
18
Time of Day

KINETIC MODEL FIT TO TROUGH DATA



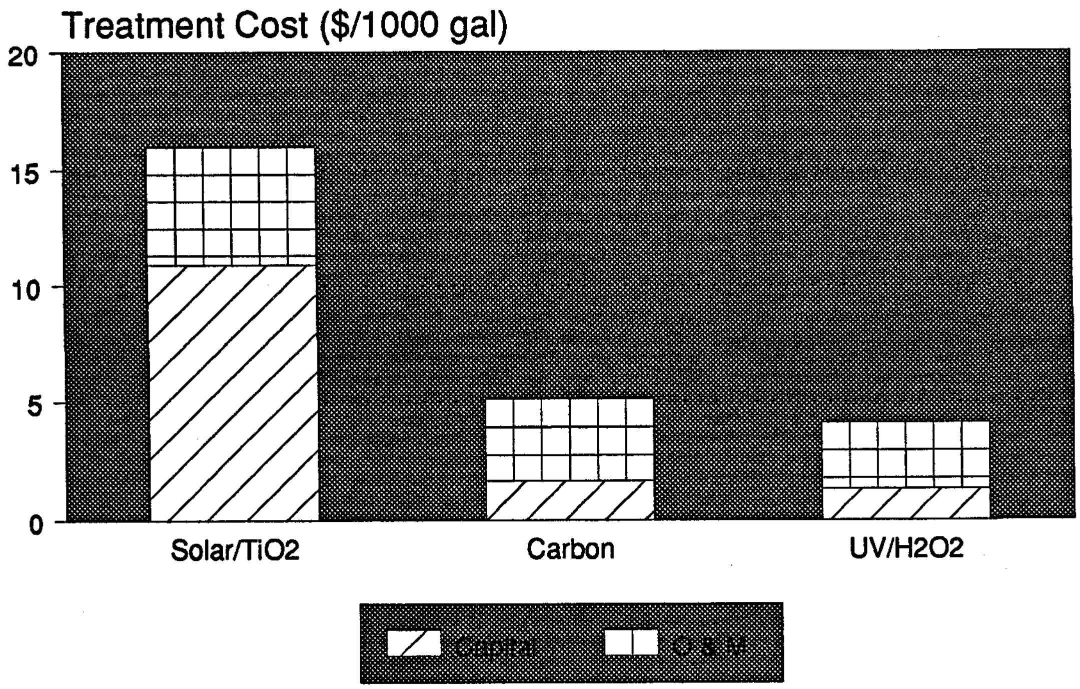
SOLTECH91

ESTIMATED 1990 SOLAR TREATMENT COST
0.1 MGD LAWRENCE LIVERMORE SITE
($/1000 gal)



SOLTECH91

ESTIMATED 1990 TREATMENT COSTS
0.1 MGD LAWRENCE LIVERMORE SITE



SOLTECH91

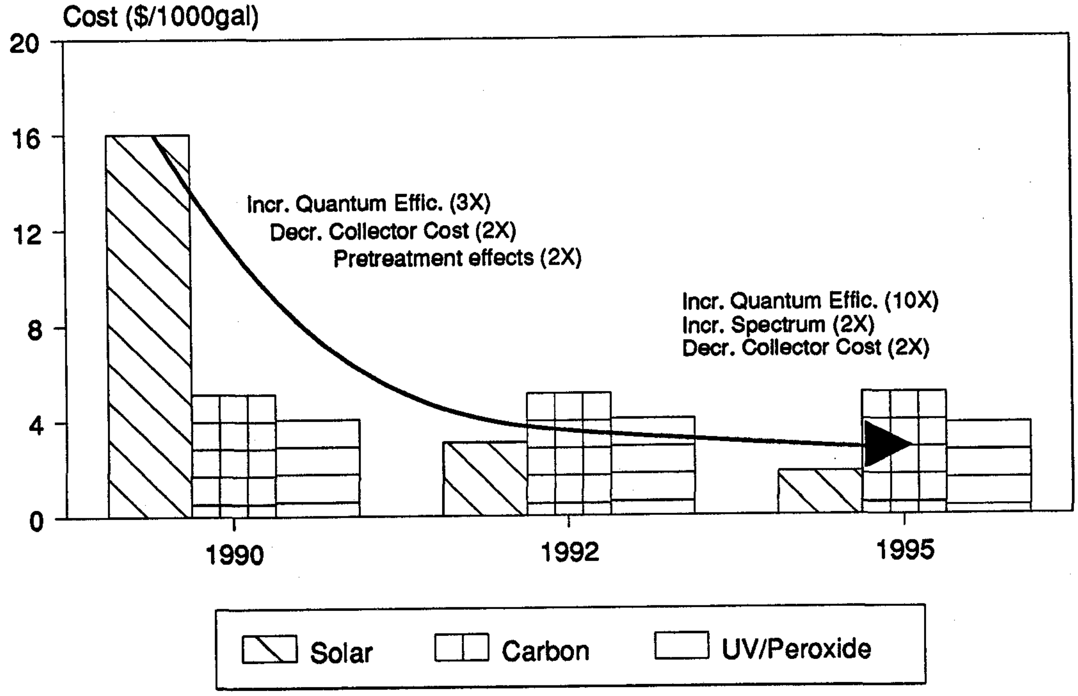
POTENTIAL IMPROVEMENTS IN SOLAR DETOXIFICATION TECHNOLOGY

- Improved photocatalyst
  - higher efficiency
  - greater overlap with solar spectrum

- Lower collector cost

- Enhanced rates through pretreatment

PROJECTED COST OF 0.1 MGD SOLAR DETOX RELATIVE TO COMPETING TECHNOLOGIES



SOLTECH91

CONCLUSIONS

- Initial market has been identified
- Current cost of solar detox is too high
- Pathway leading to cost competitiveness identified
  - Improved catalyst
  - Low-cost collector
  - Pretreatment

SERI

ABSTRACT

Market Evaluation of Solar Detoxification Technology for Aqueous Waste Streams

The Solar Energy Research Institute (SERI) of Golden Colorado has demonstrated the use of solar energy for the detoxification of contaminated aqueous waste streams. SERI contracted Radian Corporation to conduct a technical and market evaluation of the technology to help provide direction to the development program, and to identify potential applications for the process. This presentation is a preliminary summary of this work.

For the technical evaluation, Radian gathered all available technical information from SERI, and obtained technical input from SERI and Sandia personnel. Identification of market niches was based on information gathered from a review of technical databases, the technical literature, the knowledge and experience of Radian personnel, and personal contacts in the waste treatment and general environmental field. The attributes of the technology were compared with market needs to identify opportunities for, and barriers to, market entry. Factors that were evaluated include the quantities and geographic distribution of potential treatment streams; the identification of sites where potential candidate waste streams treatable by this technology can be found; the logistics of applying the technology to waste locations or vice versa; the characteristics of the wastes relative to the capabilities of the technology; and the non-technical, but significant, issues of regulatory implications and public perceptions.

BIOSKETCH

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B.S., Civil Engineering, Marquette University, Milwaukee, WI, 1973
M.S., Environmental Engineering, Marquette University, Milwaukee, WI, 1974

Mr. Osantowski has over 15 years of research, development and engineering experience in industrial water and wastewater treatment and hazardous waste remedial activities. His primary responsibilities are in the management of projects and staff involved in industrial and hazardous waste pilot testing and full-scale process design, residuals waste treatment, underground storage tank and groundwater remedial cleanup, leachate treatment, laboratory bench testing, health and safety compliance, environmental audits, air toxics programs, and analytical services.

Market Evaluation of Solar Detoxification Technology for Aqueous Waste Streams

Prepared by:

RADIAN CORPORATION

Mike Bahm

Richard Osantowski

For:

SOLAR ENERGY RESEARCH INSTITUTE

SCOPE OF CONTRACT

Review available information on SERI's solar detoxification technology and assess the technical viability and market potential based on experience and other available data

MARKET EVALUATION

- Near Term Niches

- Long Term Opportunities

FACTORS INFLUENCING NEW TECHNOLOGY SUCCESS

- Performance
- Cost
- Number of Potential Applications
- User Acceptance
- Proper Entry Applications

NEAR TERM MARKET ASSESSMENT

- Technical Advantages & Disadvantages
- Competitive Analysis
- Potential Applications
- Market Potential
- Regulatory Issues
- Market Penetration Strategy

LONG TERM MARKET ASSESSMENT

- Future Applications
- Regulatory Impact

TECHNICAL ADVANTAGES

- Low Operating Costs
- Capable of Oxidizing Most Volatile Organics
- Capable of Oxidizing Most Chlorinated Hydrocarbons
- Public Acceptance
- Zero Air Emissions

TECHNICAL DISADVANTAGES

- Limited to Simple Wastewater Types
- Number of Applications Limited to Regions of Highest Solar Insolation
- Chemical Addition for pH Adjustment and/or Oxygen Addition May be Required
- Catalyst Needs Further Research
- Area Intensive
- High Initial Capital Investment

COMPETITIVE ANALYSIS

- Primary Competition
  - Air stripping (including vapor phase carbon)
  - GAC (water phase)
  - UV/H_2O_2
- Technically Competitive
- Not Currently Economically Competitive

POTENTIAL APPLICATIONS

- Groundwater remediation and treatment for chlorinated hydrocarbons

- Wastewater treatment for refining, petrochemical, chemical and textile manufacturing industries

- South, southwest and west geographic locations

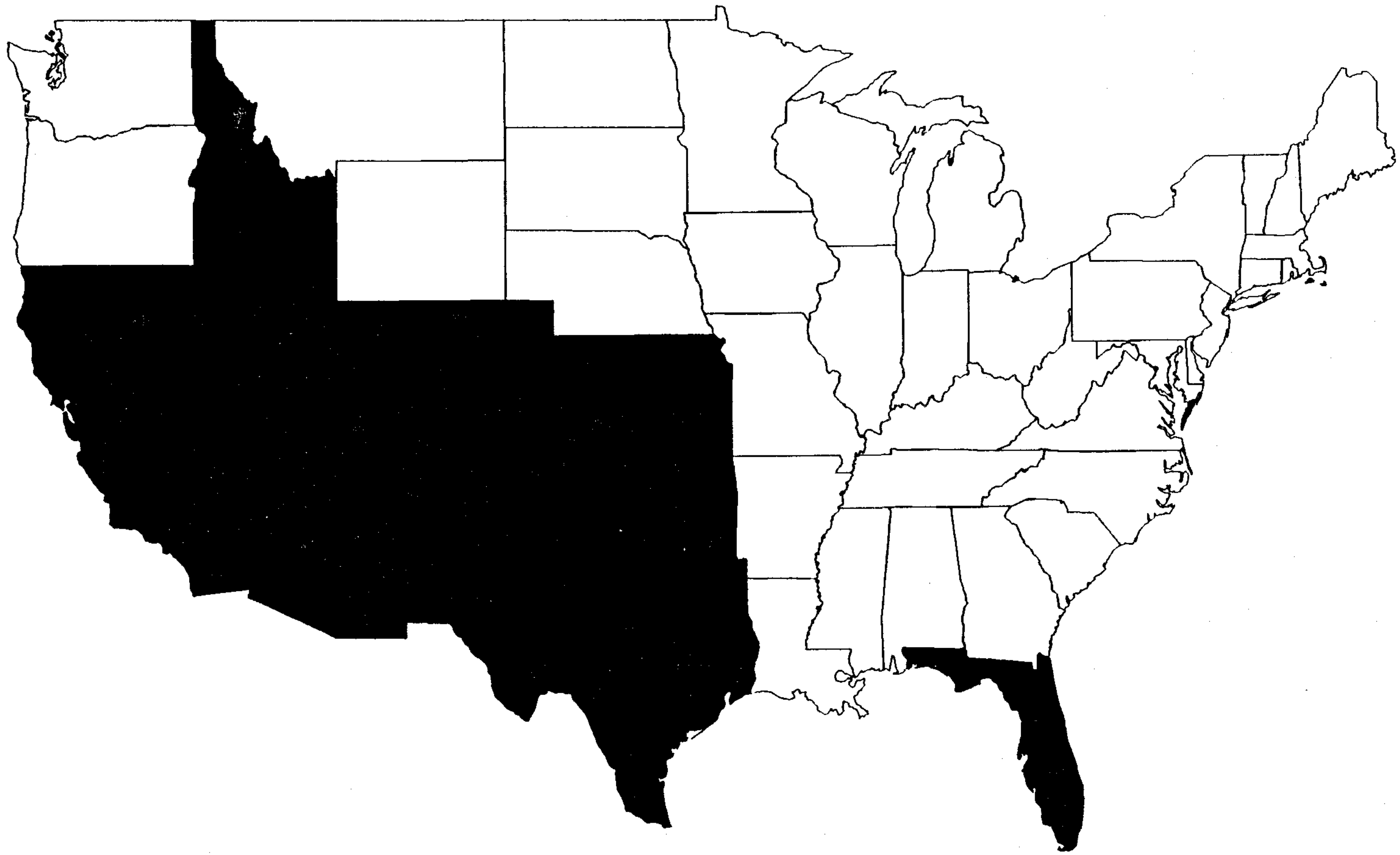
PETROCHEMICAL AND TEXTILE MILL WASTEWATER TREATMENT

- Tertiary treatment for removal of low level organics

- Oxidation step to remove inhibitory biorefractory organic chemicals

- Treatment of segregated waste streams

GEOGRAPHIC REGIONS OF HIGHEST SOLAR INSOLATION



POTENTIAL NEAR TERM MARKET

Groundwater Remediation -- Chlorinated Hydrocarbons

	Number of Potential Applications	
	Total Sites	Best Sites
Superfund	479	89
Non-Superfund	437	81
Department of Defense	3174	1587
Department of Energy	600	300
RCRA	1950	361
Total Applications		2418

AIR STRIPPER
MARKET DATA SOURCES

- Radian literature research

- Equipment Vendor Survey (1990)

- 50% are treating groundwater contaminated with chlorinated solvents (300 ug/L)

UV/H_2O_2

MARKET DATA SOURCES

- Information from companies marketing technology

- 77% are treating groundwater

- 23% are treating industrial wastewater

ESTIMATED MARKET POTENTIAL FOR INDUSTRIAL WASTEWATER TREATMENT

BASED ON ESTIMATES OF APPLICATIONS

Type of Facility	Market Estimate
Refinery	3.6×10^{9} gal./yr.
Chemical Plant (Organic)	7.7×10^{10} gal./yr.
Pesticide/Herbicide	9.9×10^{9} gal./yr.
Textile Mill	2.0×10^{9} gal./yr.
Total Volume	9.3×10^{10} gal./yr.

Assumptions: Sites with highest insolation.
20% of best sites will use the solar detox technology.
Wastewater flow of 0.5 MGD for each site.

ESTIMATED MARKET POTENTIAL BASED ON MARKET ESTIMATE OF COMPETING TECHNOLOGIES

Technology	Market Estimate
Air Stripping	1.9×10^{11} gal./yr.*
GAC	
UV/H_2O_2	1.5×10.9^{11} gal./yr.*

* Assumes an average treatment volume of 285 gallons per unit, and only 25% of current units are in regions of high solar insolation.

REGULATORY ISSUES AFFECTING COMMERCIAL APPLICATIONS

- The Resource Conservation and Recovery Act (RCRA)

- The Superfund program

- Air toxic regulation, particularly state programs, affecting the type of remediation technology used at a particular site

- User acceptance

- Community relations and public acceptance

MARKET PENETRATION STRATEGY

- Continued research and development to enhance performance and reduce capital cost

- Pilot scale operations to further demonstrate technology, develop design data, and select market niches

- Publicize performance data developed to targeted industries and technical consultants

MARKET PENETRATION STRATEGY

- Select and co-fund full scale commercial applications

- Participate in U.S. EPA Superfund Innovative Technology Evaluation (SITE) program

LONG TERM OPPORTUNITIES

- Future Superfund sites with chlorinated organics contamination

- Tertiary treatment in petrochemical industries

- Drinking water treatment

POTENTIAL NEAR TERM MARKET

Industrial Wastewater Treatment

	Number of Potential Applications	
	Total Sites	Best Sites
Petrochemical Facilities		
Refineries	190	98
Chemical Plants	9298	2118
Pesticide/Herbicide Facilities	1372	268
Textile Facilities	1364	54
	12,224	2538

POTENTIAL LONG TERM OPPORTUNITIES

Future Superfund Sites-Chlorinated Hydrocarbon Contamination

	Number of Potential Applications	
Application	Total Sites	Best Sites
Groundwater Remediation		
Future Superfund	1092	202

Recent Results and Implications of Large-Scale Solar Detoxification of Water Experiments* At Sandia National Laboratories

Jim Pacheco

Solar Thermal Collector Technology
Division 6216
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Albuquerque, NM 87185

ABSTRACT

Sandia National Laboratories' part in the Department of Energy's Solar Detoxification of Hazardous Waste Initiative is focused on conducting large-scale solar photocatalytic experiments. Sandia's efforts support fundamental laboratory research performed by the Solar Energy Research Institute (SERI), which will lead to the first field experiment of the technology at Lawrence Livermore National Laboratory by around July 1991. In Sandia's facility which consists of six parabolic troughs in series, water, spiked with a contaminant, flows through glass pipe reactors centered at the focus of the troughs. The ultraviolet portion of the concentrated sunlight activates a titanium dioxide catalyst to form oxidizers which have the ability to decompose many organic compounds. The process has two broad applications: remediation of groundwater and treatment of industrial effluents. Sandia's work represents the first attempt to extend the process to a practical scale.

We have conducted numerous tests with water contaminated with dilute concentrations (100 to 10,000 parts per billion) of chlorinated solvents (e.g., trichloroethylene (TCE), trichloroethane (TCA), perchloroethylene (PCE), and methylene chloride), salicylic acid, and textile dyes using a large parabolic trough. Recent results from these experiments and the implications to system configurations and to the practicality of the process will be discussed.

* This work is supported by the U.S. Department of Energy under contract DE-AC04-76DP00789. SAND91-0628A

Recent Results from Sandia's Large-Scale Solar Detoxification of Water Experiements

James E. Pacheco

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Albuquerque, NM 87185

Sandia
National
Laboratories

Objectives of Solar Detoxification of Water Project

I. Develop a Solar-Driven Photocatalytic Process To Destroy Organics In Water

II. Perform Large-Scale Tests at Rates Close to Actual Processing Rates Using Sunlight. Supports SERI's Fundamental Laboratory Work

III. Study the Destruction of Organic Compounds In Water Under Various Process and Solar Conditions

IV. Experimental Results From This System Provide Input to the Design And Economic Assessment of a Solar Detoxification System

V. Well Defined System That Can Be Field Tested At LLNL This Summer

Sandia
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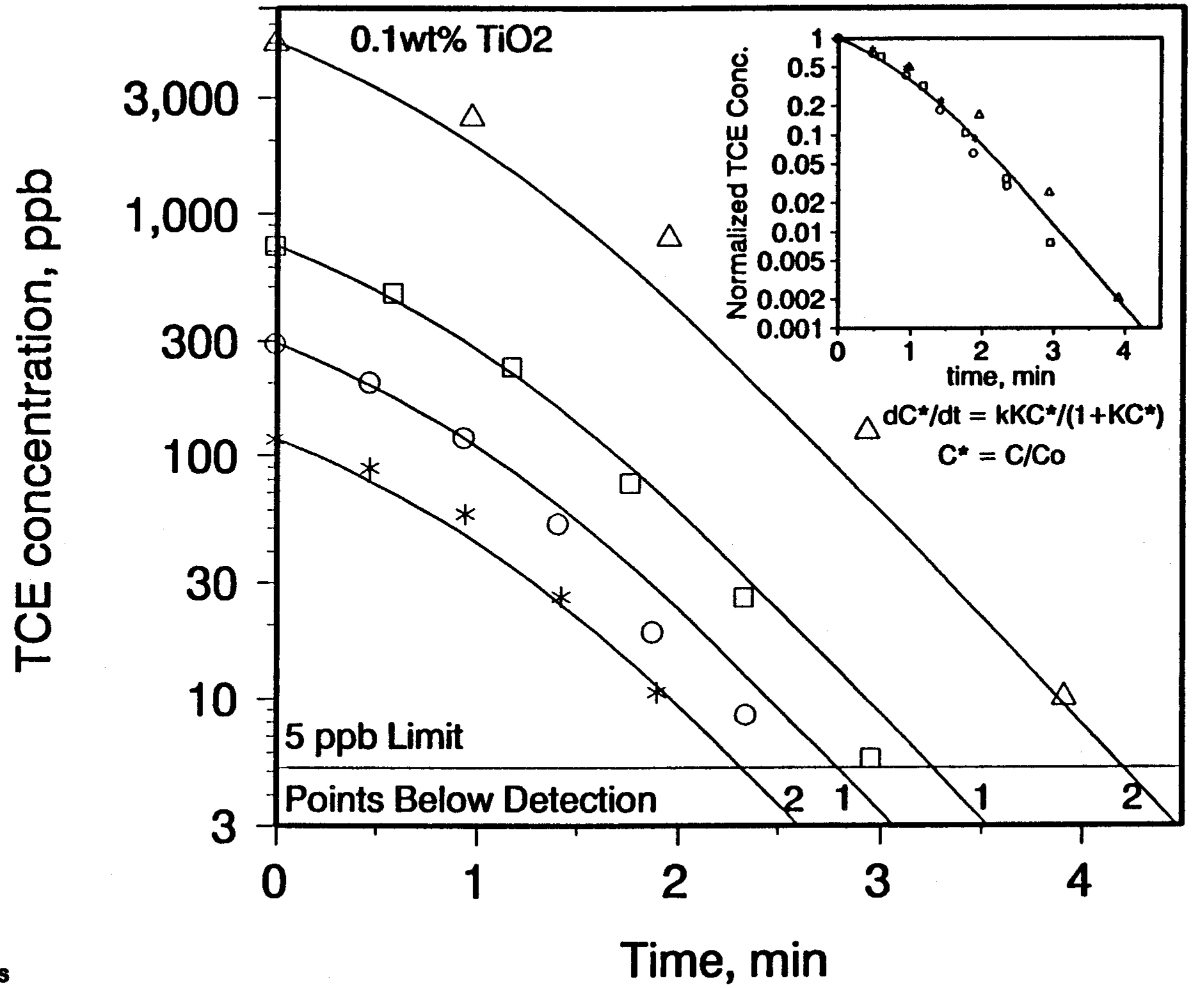
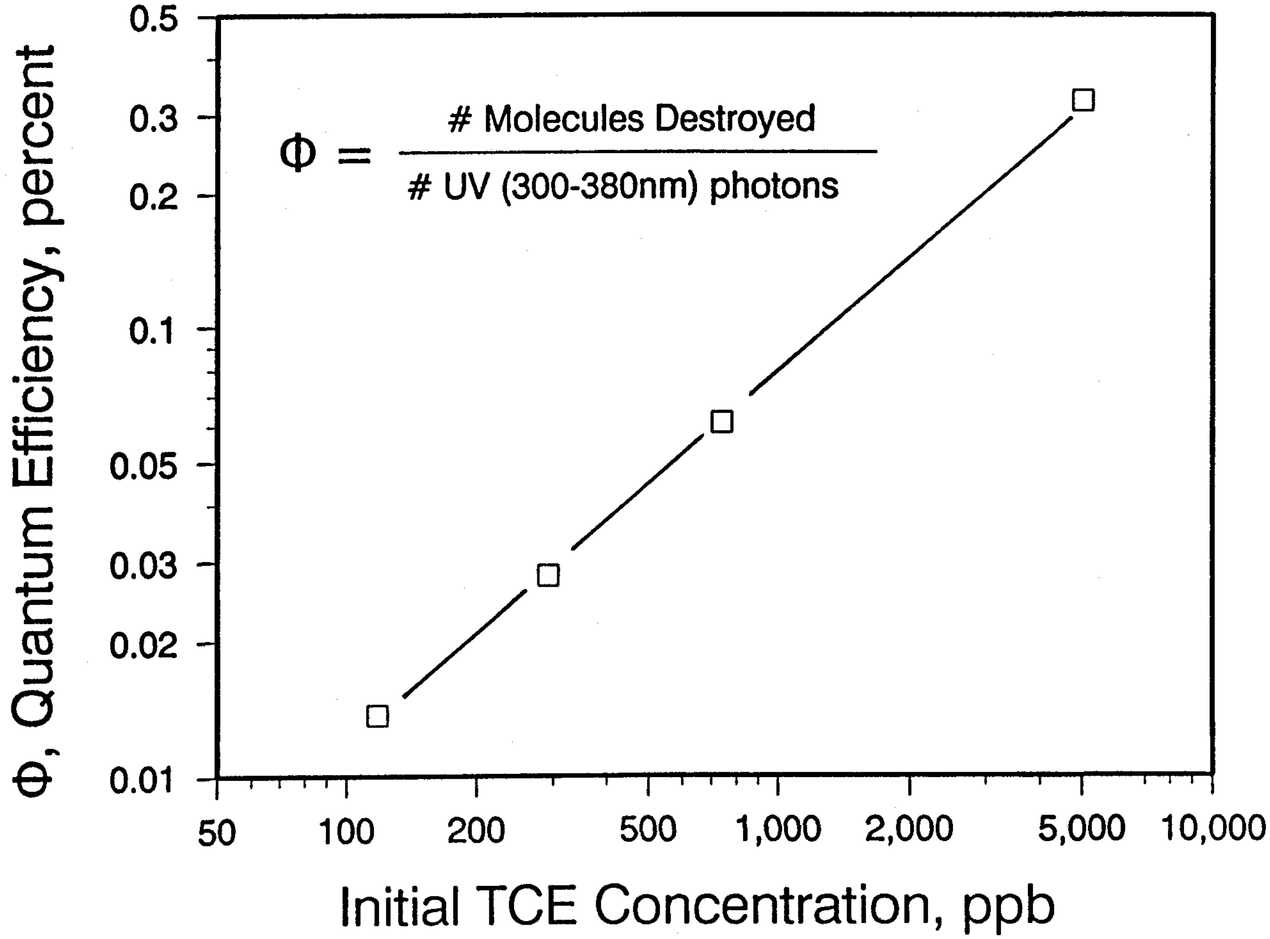
Laboratories

Effect of Initial TCE Concentrations



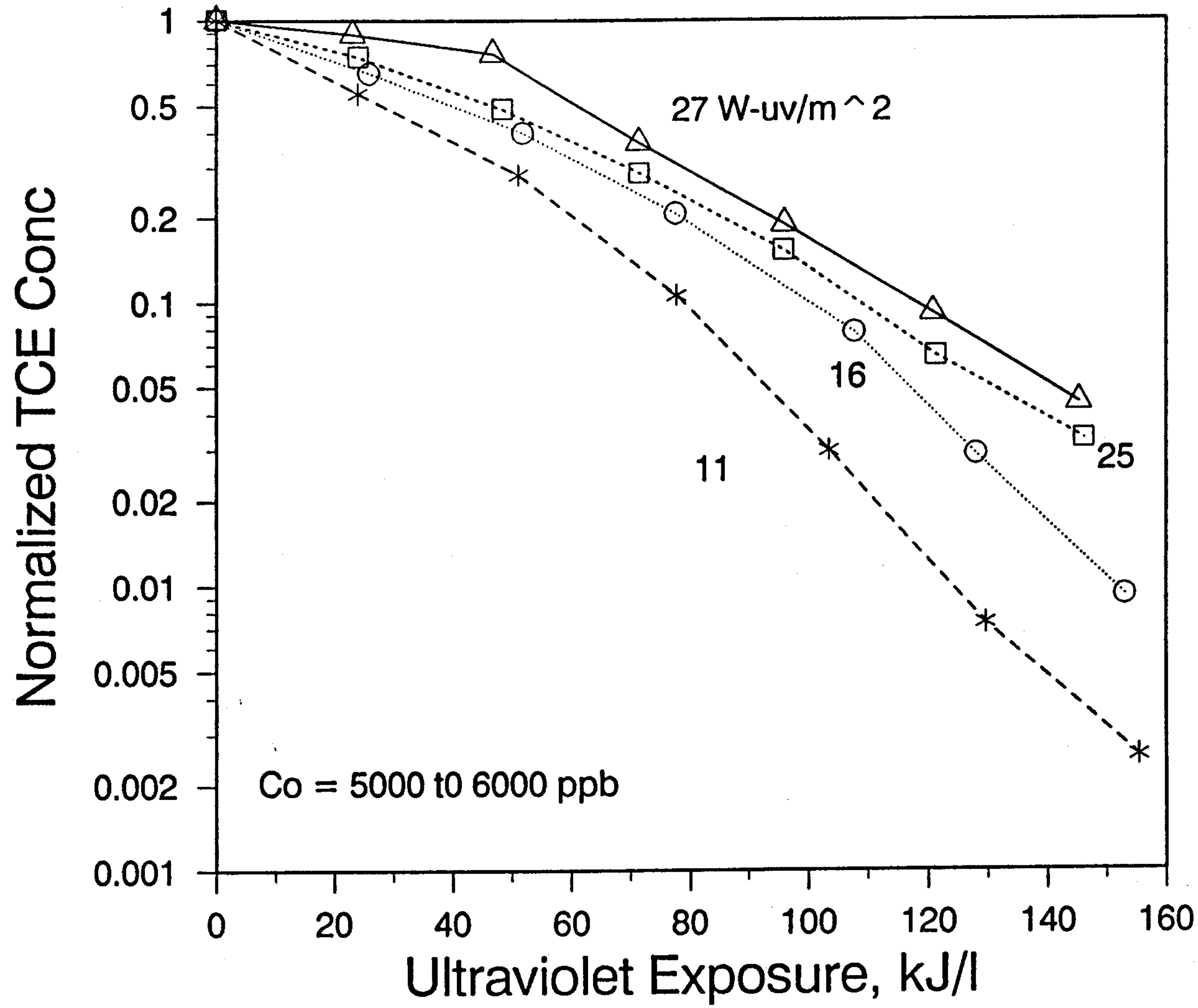
Sandia National Laboratories

The Process is More Efficient at Higher Initial Concentrations



Sandia National Laboratories

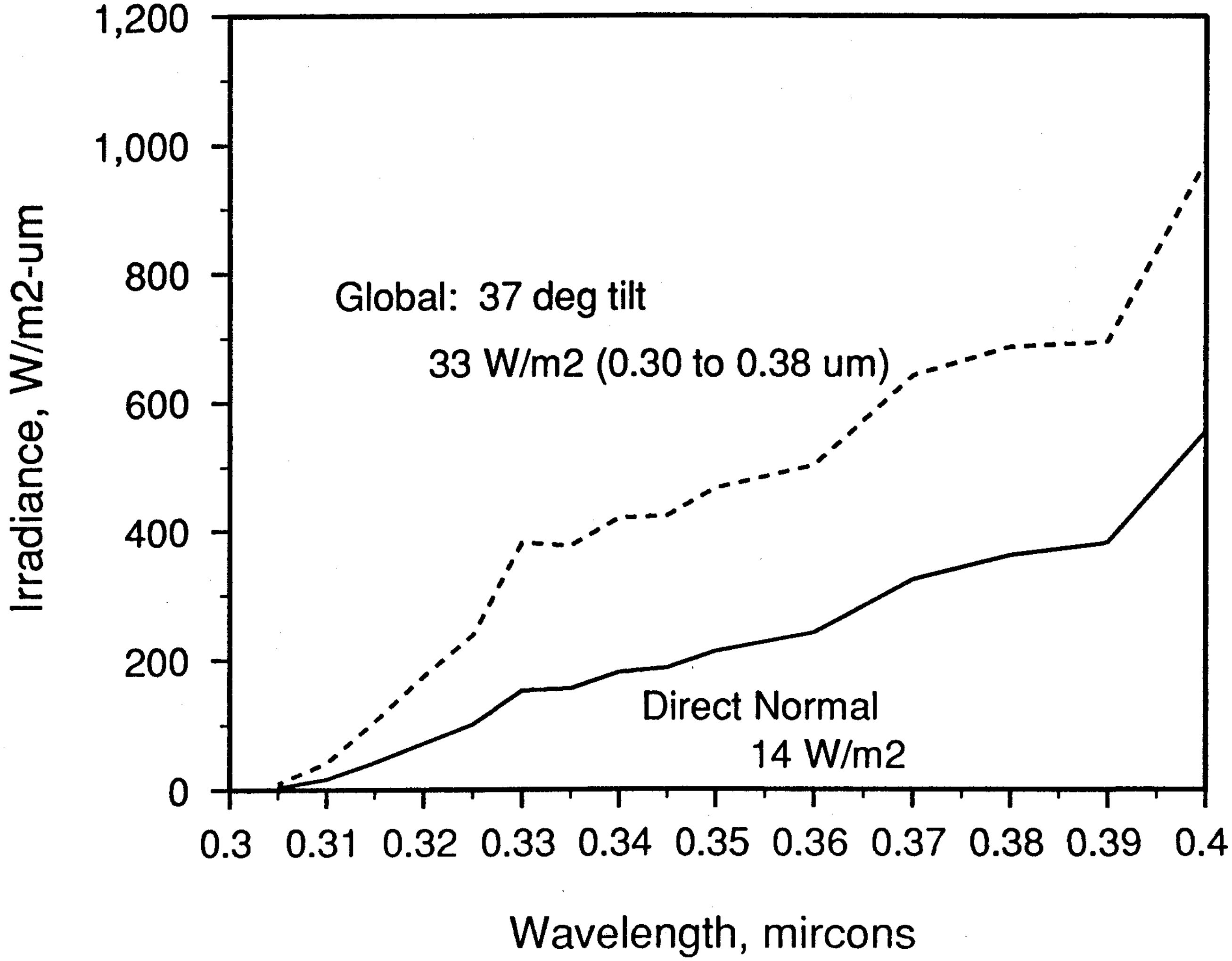
The Process is More Efficient at Lower Intensities



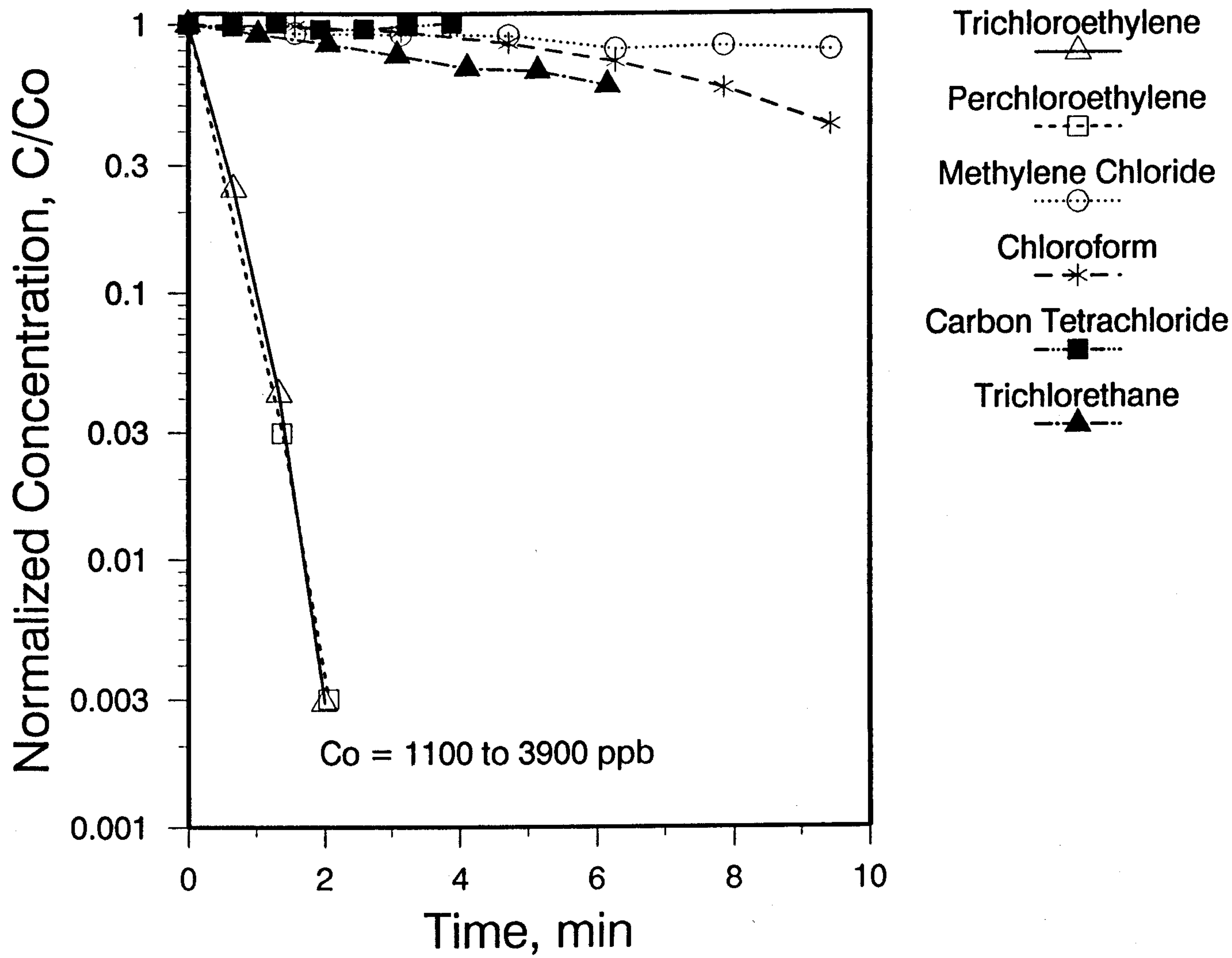
$$\int_{o}^{t_s} I''_{\Delta\lambda eff} \, dt$$

Sandia National Laboratories

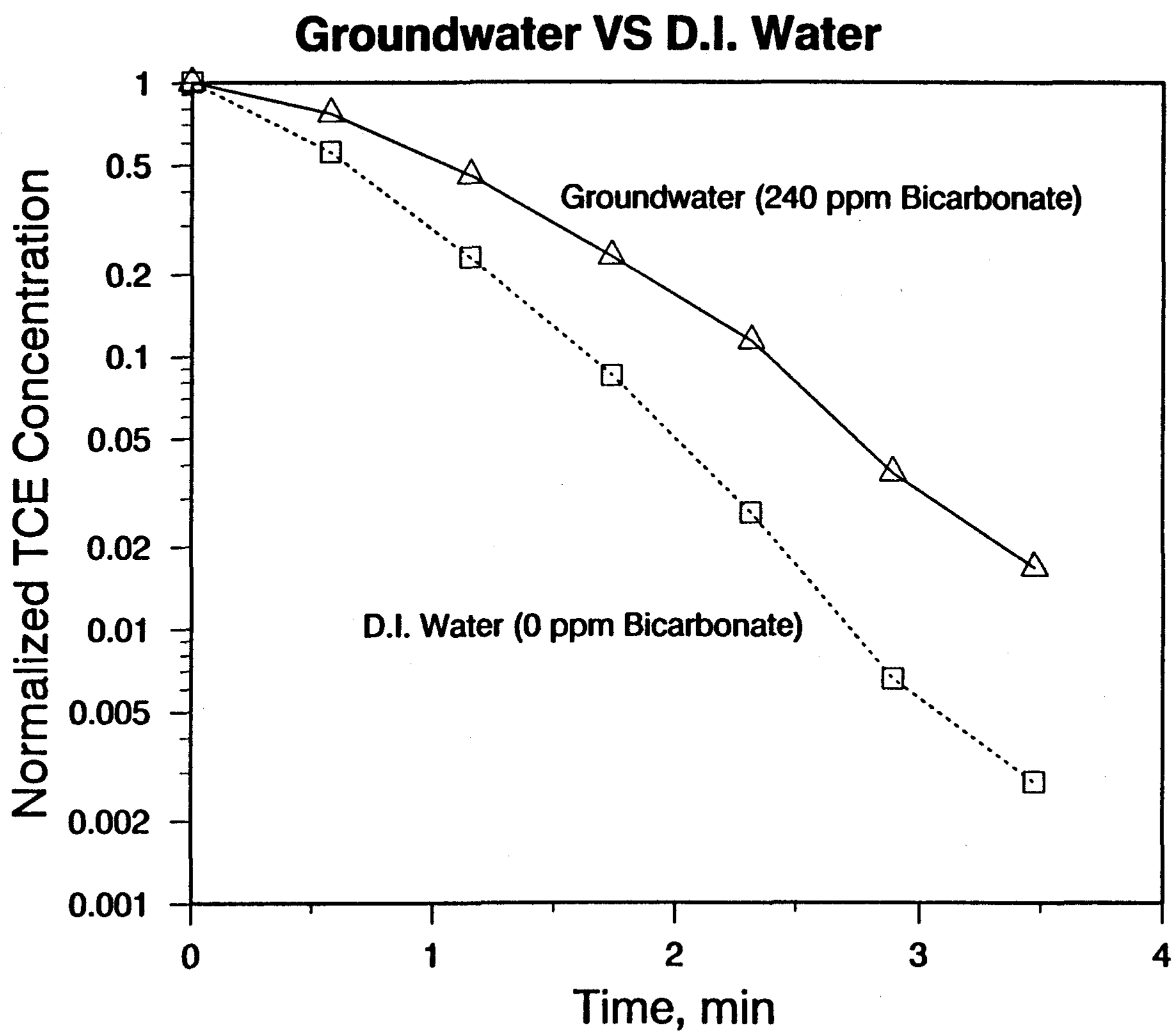
Solar Spectrum: 0.30 to 0.40 microns

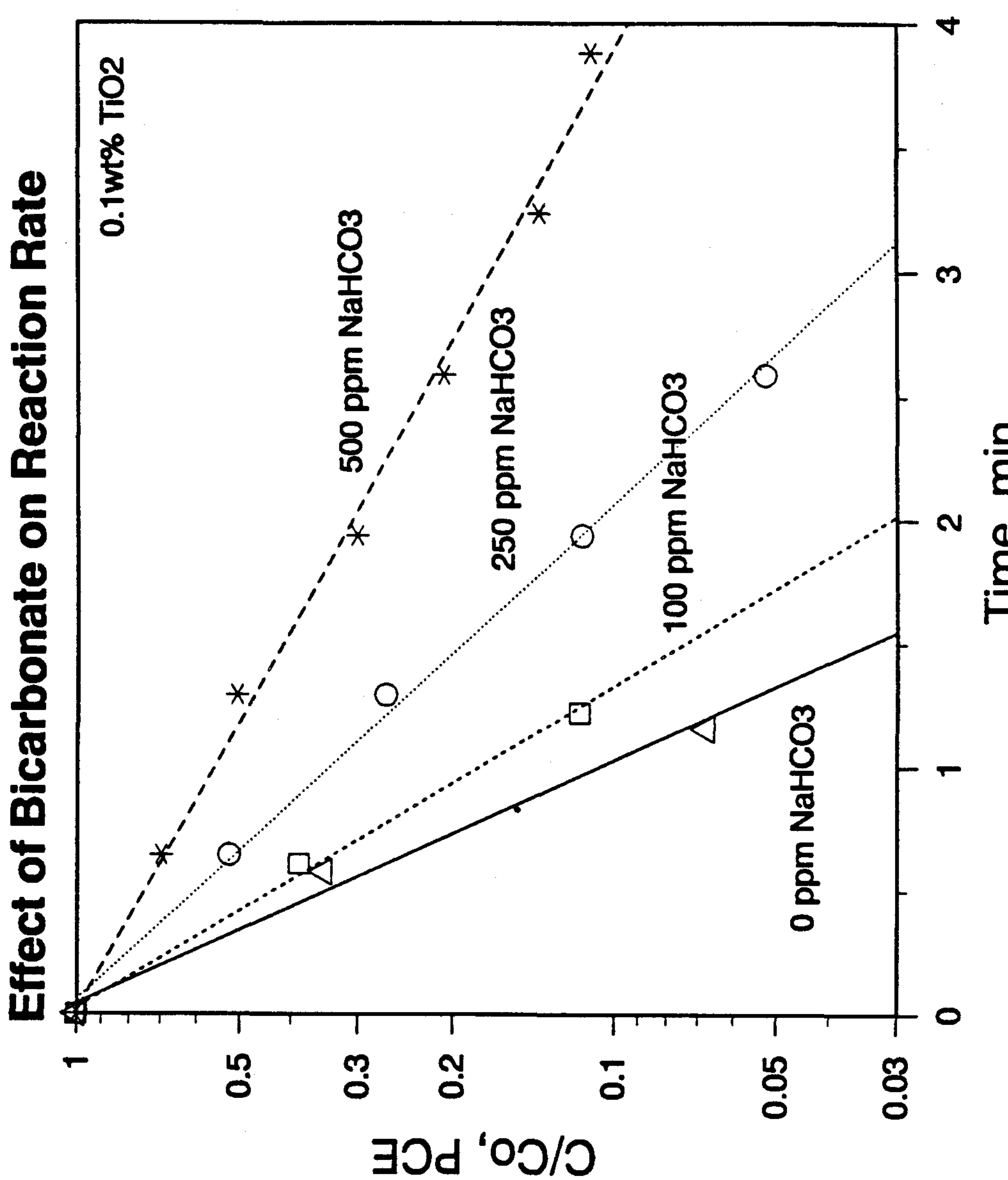


Chlorinated Alkenes React The Fastest



Sandia National Laboratories


Groundwater VS D.I. Water
Normalized TCE Concentration
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0
1
2
3
4
Time, min
Groundwater (240 ppm Bicarbonate)
D.I. Water (0 ppm Bicarbonate)


Effect of Bicarbonate on Reaction Rate
0.1wt% TiO2
500 ppm NaHCO3
250 ppm NaHCO3
100 ppm NaHCO3
0 ppm NaHCO3
C/Co, PCE
1
0.5
0.3
0.2
0.1
0.05
0.03
Time, min
0
1
2
3
4

Conclusions

I. Higher Initial Concentrations Yield Higher Quantum Efficiencies

II. Process More Efficient At Lower Intensities

- Kinetics Favor Lower Intensities
- Nonconcentrating Collector Can Use Diffuse UV Radiation

III. Process Most Effective On Chlorinated Alkenes

IV. Bicarbonates Inhibit Reaction

- pH Adjustment Can Help But Adds To Cost

Sandia
National
Laboratories

SOLAR DETOXIFICATION OF CONTAMINATED WATER:

THE DESIGN AND FABRICATION OF A PROTOTYPE LOW-COST CONCENTRATOR SYSTEM

KEN MAY
RANDY GEE

INDUSTRIAL SOLAR TECHNOLOGY

Industrial Solar Technology, under contract to the Solar Energy Research Institute, is starting projects to design and fabricate a prototype, low-cost concentrator system to be used to detoxify contaminated water. The projects have two major elements: the first aimed at developing a concentrator that can be installed at a cost of $50/m^2; the second to produce a fixed bed reactor with equivalent or better performance than reactors using a slurry of titanium dioxide.

The concentrator project builds on existing IST technology, while taking advantage of the differences between concentrators built for thermal and detoxification applications. Detoxification systems favor larger diameter receivers since the processes occur at ambient temperatures, and because the desired concentration ratios are generally lower. The low pressure capability of glass reactors, and higher pressure drop through packed bed reactors compared to open tube thermal absorbers, also favor larger receiver diameters. A larger receiver target translates into reduced optical requirements that can lead to reductions in concentrator costs.

The current IST concentrator weighs 5.4 kg/m^2 (1.1 lb/ft^2) of active aperture area. This low weight is obtained using aluminum in an efficient design that employs the reflective surface as a structural member. Though survivability criteria, wind, snow and hail, determine structural requirements, weight reductions, to take advantage of reduced optical accuracy, may be possible by reducing the rim angle of the concentrator to increase the ratio of aperture area to area of reflective surface. Additional savings can result from reductions in the manufacturing cost of the concentrator, the tracking/drive system and receiver supports. Current practice at IST is to gang four rows of collectors together so that 335 m^2 (3,600 ft^2) of solar collectors track the sun using a single drive/control unit. For a detoxification system, the drive area could be increased.

Field installation is a significant cost component. Existing installation of IST concentrators is quite efficient, largely a result of their low weight, that eliminates the need for mechanical lift equipment. However, the support pylons must be accurately located on their reinforced concrete foundations. Ideas will be explored to speed this process involving the construction of large-scale jigs to set the holes for drilling, and to align the pylons.

The reliability of the IST concentrator system has been demonstrated in extreme operational environments. The performance of the system for detoxification applications is greatly enhanced through the use of an aluminized acrylic film, that is highly reflective in the near UV range. The all aluminum concentrator construction, the simplicity of the drive system, and the proven reliability of the control system all help to minimize operational and maintenance costs.

The cost reducing methods described above will be investigated analytically, and through the testing of prototypes. Ultimately, these improvements will be embodied in a prototype row to be installed at the SERI test site. Cost studies ranging up to a production level of 100,000 m^2 (1,080,000 ft^2) will project production and installation costs in comparison to the installed concentrator goal of \$50/m^2 (\$4.65/ft^2).

IST is collaborating with TDA Research to develop prototypes of an efficient fixed bed photochemical reactor. The aim is to develop such a reactor as a replacement for slurry reactors, that present difficulties in removing titanium dioxide catalyst from the effluent stream. The photochemical reactor should allow high rates of reaction to decompose the organic contaminant (trichloroethylene, TCE, for the purpose of this study), partly through promoting efficient mixing to limit mass transfer resistance. The reactor should also present minimal resistance to flow so that large flow volumes can be processed in long reactor strings. In addition, the costs of operating and maintaining the catalyst should be low, and it should be easy to regenerate and replace.

To achieve the above goals, several catalyst support materials and reactor configurations will be investigated. The first support material to be considered is titanium dioxide impregnated onto fiberglass cloth. SERI has carried out preliminary investigations on such a commercial product called "Nulite". TDA will also deposit catalyst on metal screens and foams as alternative catalyst support materials. These catalyst materials will be evaluated arranged in various reactor configurations. A baseline arrangement is simply to coil the material inside the round reactor tube. However, it is likely that this arrangement produces too great a pressure drop to be acceptable in a large commercial system. A promising alternative is a cross flow reactor. Here sufficient catalyst on its support material (using the alternatives listed above) is employed to intercept all the incident near UV light. However, the flow path is largely unrestricted, so as to minimize pressure drop, apart from the placement periodically of baffles, that promote efficient mixing within the reactor. A variation on the backflow reactor is to reduce the thickness of catalyst material, and to incorporate an aluminized back reflector. This approach could reduce the quantity of catalyst material required and promote greater efficiency in its use, by illuminating the back as well as the front surface of the catalyst. This could be advantageous from a kinetic standpoint by reducing the effective concentration of sunlight at the catalyst surface. In yet another performance enhancement, a sol-gel anti-reflective coating will be applied to the glass containment tube. Such a coating, optimized in the UV range can increase transmittance by about 6%, over untreated glass.

The performance of the proposed catalyst and reactors will be evaluated on a pilot scale using an artificial light source. The optical characteristics of a small reactor will be measured, as well as pressure drop and mixing. Accurate chemical analysis will allow the reactivity of the catalyst to be measured, as a function of dissolved oxygen content, pH and flow rate. Data analysis will allow reaction rates to be calculated as well as catalyst deactivation rates. The laboratory work will conclude with an evaluation of the materials proposed for use in the reactor, and a cost estimate of producing the reactor on a large scale.

Following the laboratory work, several full scale reactor prototypes will be fabricated. These will be installed in IST's commercial parabolic trough collector system at the SERI test site. The project team will carry out initial checks and evaluations on the prototype reactor system.

Solar Detoxification of Contaminated Water

P13-G0711214

The Design and Fabrication of a Prototype Low-Cost Concentrator System

P13-G0711213

Design Objectives

- Overall goal: $50/m^2 installed concentrator cost
  - Lightweight structure
  - Low manufacturing costs
  - Low installation costs
- Operational goals
  - High performance in near UV
  - Reliable
  - Low O&M costs
  - Flexibility
  - Containment of toxics

P13-G0711212

System Characteristics

	Thermal	Detoxification
Concentration ratio	30-100	5-50
Operating temperature	Up to 300°C	Ambient
Receiver pressure	High	Low
Receiver pressure drop	Low	High (for packed beds)

P13-G0711215

Lightweight Structure

- Concentrator as a structural member
- Optimization of rim angle

Rim angle	90°	72°
Aperture/surface area	0.87	0.93

- Survivability criteria

  Wind

  Snow

  Temperature

  Hail

P13-G0711211

Manufacturing Cost Reductions

- Drive/controls
  - Increase drive area
  - Increase component manufacturing tolerances
- Concentrator
  - Reduce forming accuracy
  - Simpler receiver supports
- Economies of scale
  - Aluminum
  - Reflective film
  - Components

P13-G0711230

Installation Cost Reductions

- More efficient layout of concrete caissons
- Faster alignment of support pylons
- Larger drive area
- Fewer tracking/drive controls
- Economies of scale

O&M Cost Reductions

- Maintenance free materials
  - All-aluminum concentrators
  - Glass reactor
  - Permanently lubricated bearings
- Easily accessible/removable reactors
- Few and simple moving parts
  - Large drive area
  - Off-the-shelf components
- Minimum leak points

P13-G0711232

Project Plan

Analysis
- Optics
- Drive accuracy
- Manufacturing costs
- Installation costs

Testing
- Simulated drive string
- Concentrator assembly jigs
- Foundation layout jig
- Pylon alignment procedures

Fabrication
- Low-cost concentrator prototypes

Installation
- Prototype concentrator row
- Performance verification

P13-G0711233

Reactor Characteristics

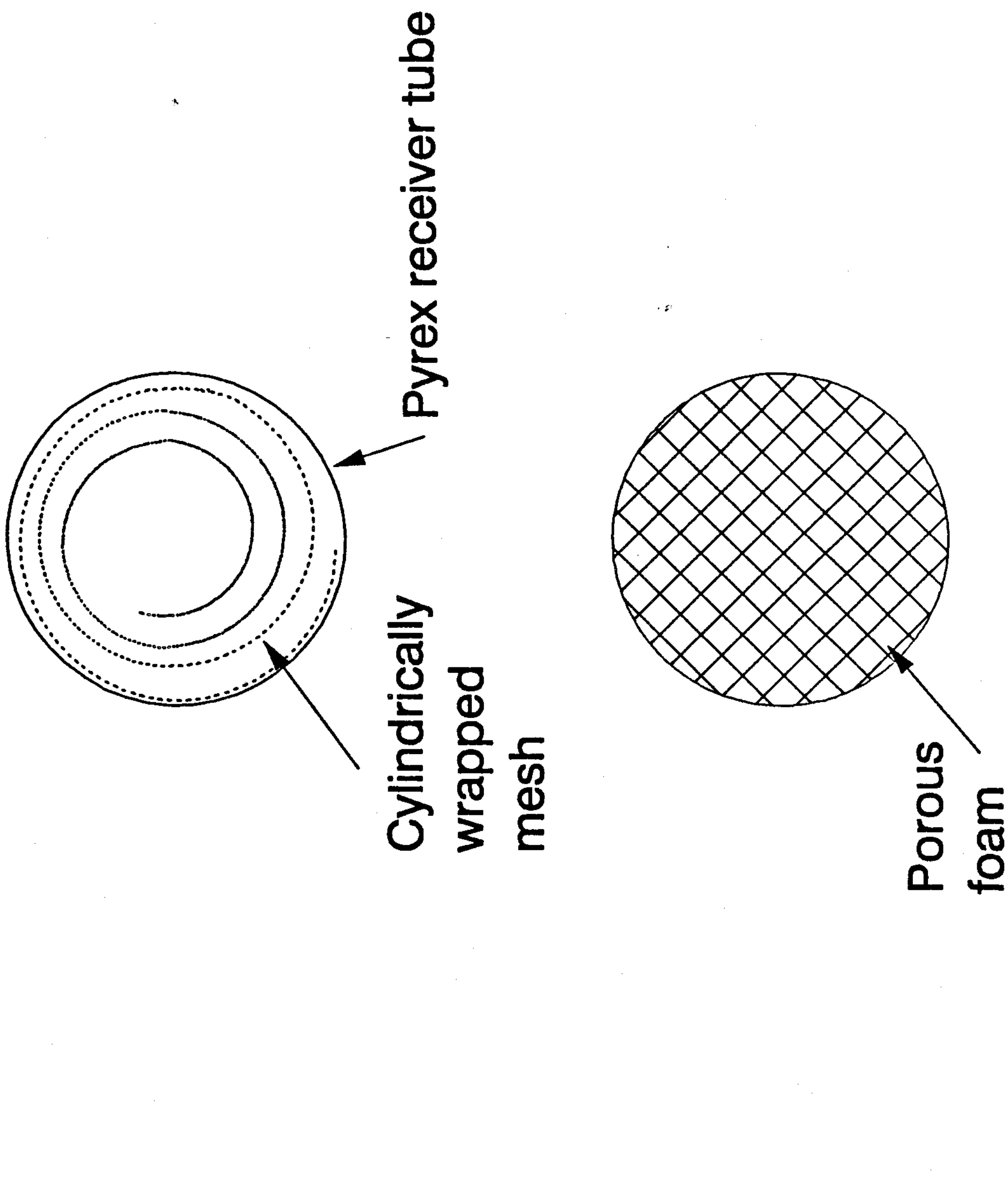
- Fixed catalyst support
- High reaction rate
- Reaction rate independent of flow (chemical reaction rate dominant)
- Minimum ΔP
- Low capital cost
- Low maintenance cost
- Easy regeneration/replacement
- High glass transmittance

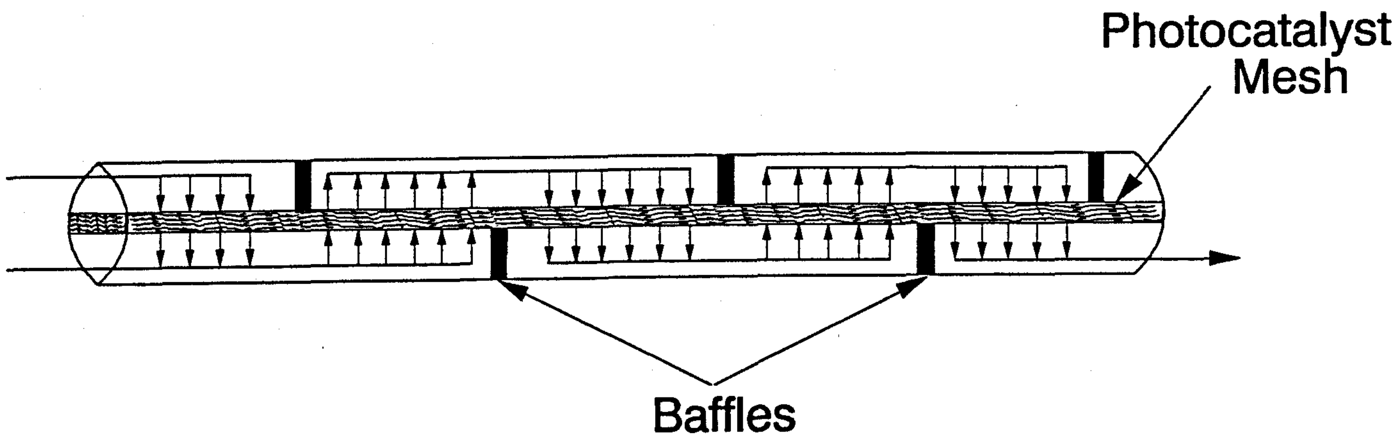
P13-G0711225

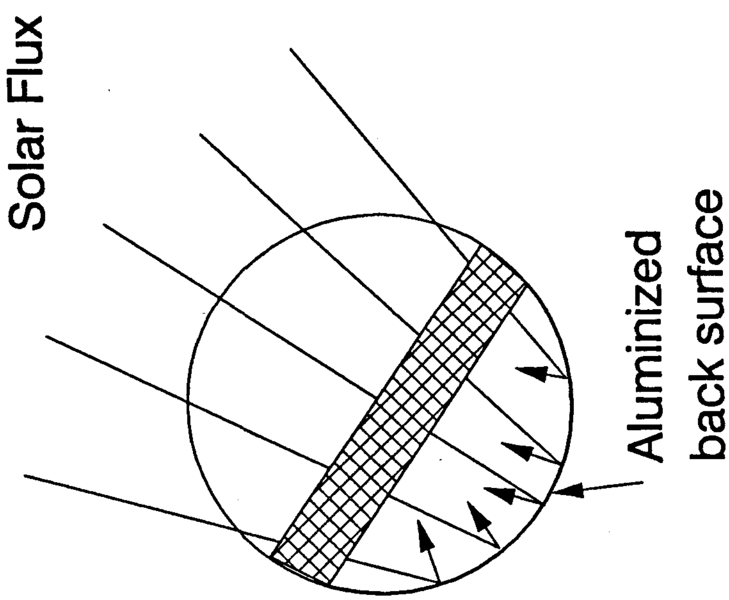
Reactor Configurations

- Coiled fiberglass cloth, metal screen, or metal foam
- Cross flow
- Rear reflector
- Anti-reflective coating on glass

P13-G0711226


Pyrex receiver tube
Cylindrically wrapped mesh
Porous foam


Photocatalyst
Mesh
Baffles



Solar Flux
Aluminized back surface

Pilot Scale Reactor Evaluation

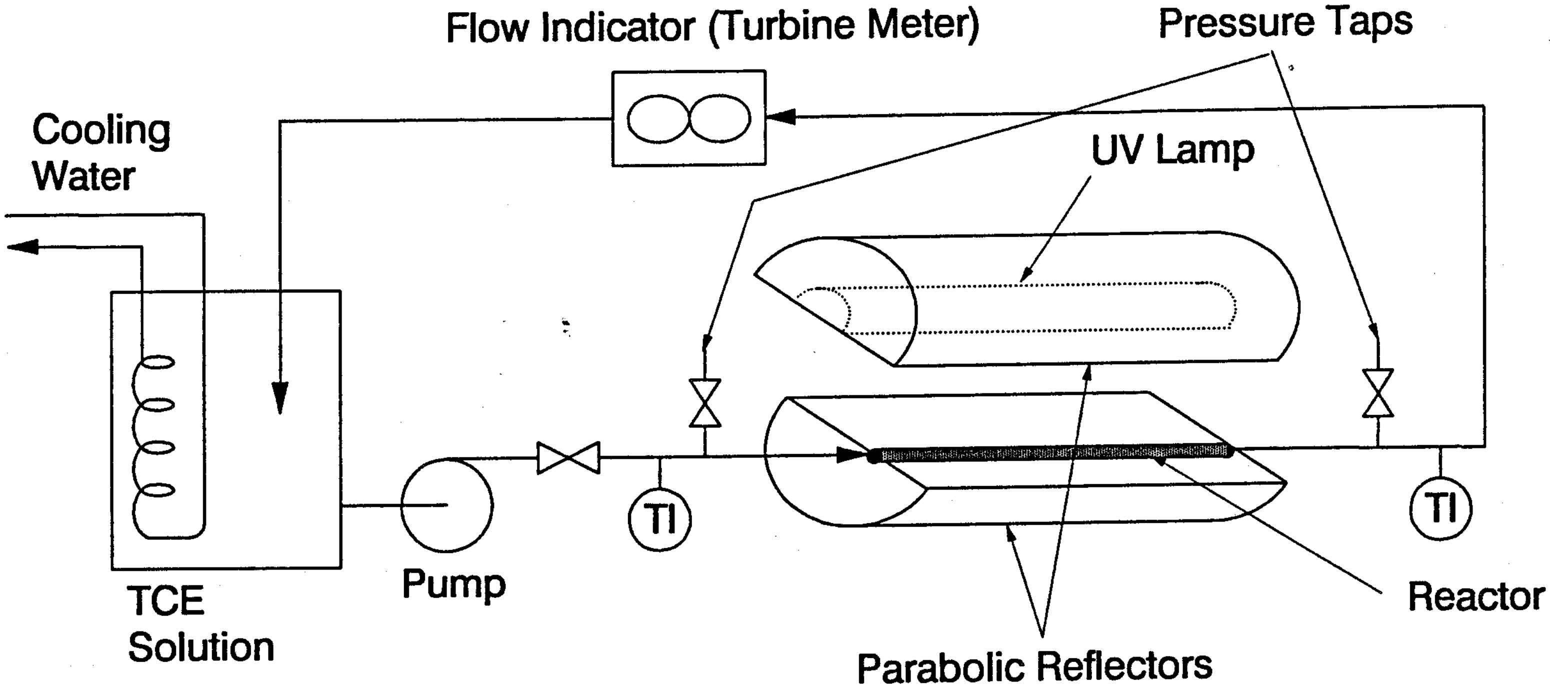
Apparatus

- 3 ft reactor
- UV light source
- Small parabolic trough concentrator

System parameters

- Pressure drop
- Mixing
- Optical characteristics
- Reactivity to TCE
- Dissolved oxygen
- Ph
- Flow rate

P13-G0711227


Flow Indicator (Turbine Meter)
Pressure Taps
Cooling Water
UV Lamp
TI
TI
Pump
TCE Solution
Reactor
Parabolic Reflectors

Pilot Scale Results

- TCE reaction rate
- Catalyst deactivation
- Flow characterization
- Materials evaluation
- Receiver cost estimate

P13-G0711228

Scale-Up Activities

- Fabrication of full-scale reactor prototypes
- Installation of reactors in commercial parabolic trough concentrators
- Initial system checkout and evaluation
- Updated cost estimates

P13-G0711229

SOLAR DETOXIFICATION OF WATER: LABORATORY RESEARCH

Daniel M. Blake, Solar Energy Research Institute
Golden, Colorado

The destruction of hazardous organic chemical contaminants in water by photocatalytic oxidation over semiconductors is the subject of worldwide interest. This paper reviews the laboratory research project being carried out by the US Department of Energy to develop a unit operation for water decontamination using solar energy as the light source. This part of the program includes in-house research at the Solar Energy Research Institute and Sandia National Laboratories, subcontracted work at universities, collaborative work with industry, and the tracking of progress of other research groups in laboratories throughout the world.

Development of a viable solar water treatment process requires an understanding of the physical and chemical phenomena that influence the conversion of light to chemical energy. These include (1) transmission of the light (global horizontal solar or concentrated direct normal solar) through the water to be treated to the catalyst, (2) physical events within the catalyst particle, (3) chemistry initiated at the catalyst surface, and (4) chemistry that may propagate through the aqueous phase.

Significant progress has been made in understanding each of the steps in the process. The influence of the water quality (hazardous contaminant(s), natural organic and mineral matter, and particulates) on these steps has been broadly identified. This has been achieved in work with synthetic water mixtures and in working with samples of contaminated water from a number of industrial and government sites. The latter have been particularly important in identifying water quality factors that require pre- or post-treatment operations in conjunction with the solar step.

Treatability studies on samples of contaminated water and on an extended range of organic compounds will be expanded in the near future through work subcontracted at an outside laboratory This interaction will aid in identifying appropriate applications for the process and provide expertise in development of the overall treatment strategy for water at contaminated site or from a process waste stream.

SOLAR DETOXIFICATION OF WATER

Solar Energy Research Institute
Sandia National Laboratories

LABORATORY RESEARCH PROGRAM

DANIEL M. BLAKE

CO-WORKERS
SERI/SNL

Rita Goggin

Mike Taylor

Kim Bair

Mark Peterson

Brian Gregg

Craig Turchi

Mike Prairie

John Webb

dmb-108

SERI

LABORATORY RESEARCH
OBJECTIVES

- Develop a more efficient (active) photocatalyst
- Identify key water quality factors which influence process efficiency
- Expand the range of applicability of the photocatalytic process

dmb-102

RESEARCH PROGRAM

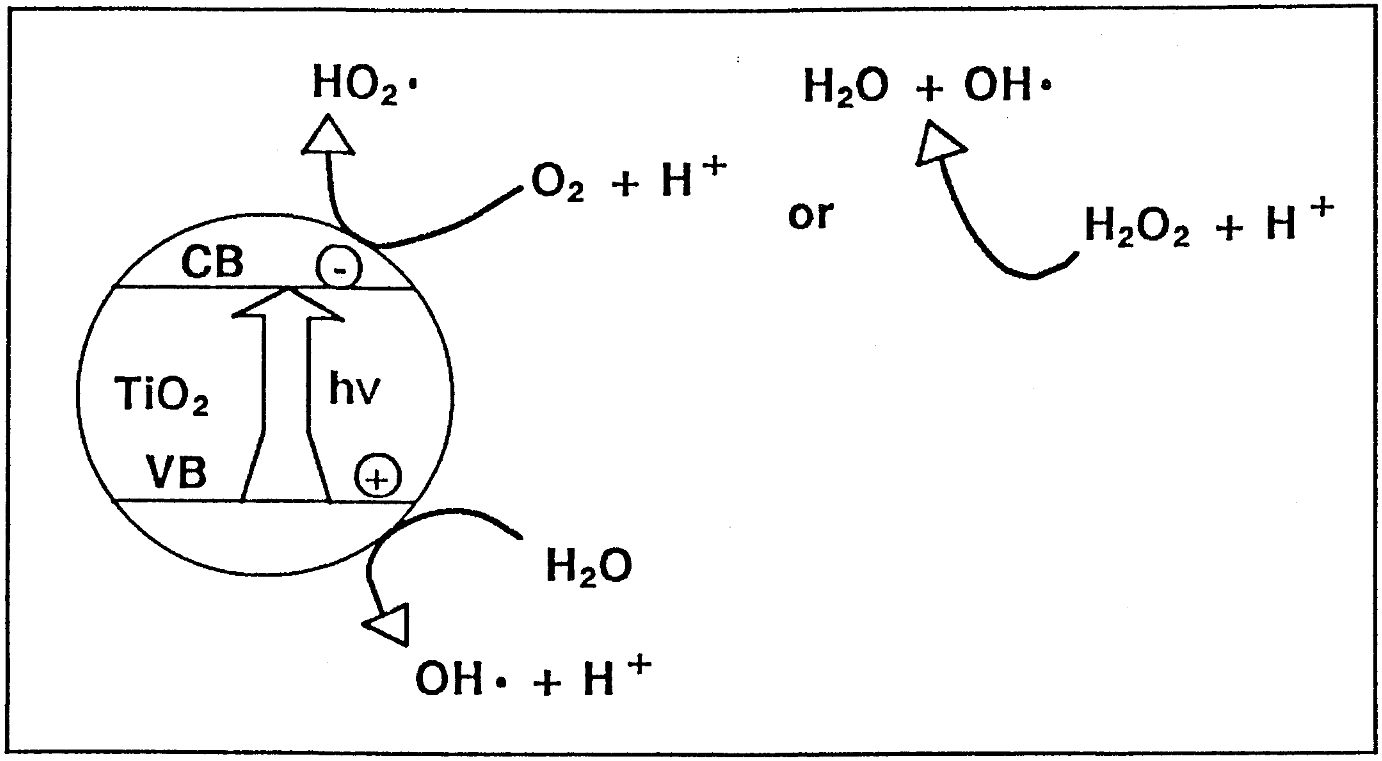
- In House Research
  SERI/SNL

- Subcontracted Research
  Brown University
  U. N. Carolina - Chapel Hill
  University of Colorado
  University of Arizona
  Other University(s) - tbd
  Water Treatment Company - tbd

- Monitor work of laboratories world wide

dmb-103

Generation of Primary Radicals at Surface of Irradiated TiO_2 Particles in Water



AG123-G0696101

Radicals Formed on Irradiated TiO_2 and Their Reactions

Electron-Hole Pair Formation

$$TiO_2 \xrightarrow{h\nu} TiO_2^- + OH\bullet \quad (TiO_2^+,\ H_2O)$$

Electron Removal from TiO_2^- (CB)

$$TiO_2^- + O_2 + H^+ \longrightarrow TiO_2 + HO_2\bullet$$
$$TiO_2^- + H_2O_2 + H^+ \longrightarrow TiO_2 + H_2O + OH\bullet$$
$$TiO_2^- + H^+ \longrightarrow TiO_2 + 1/2\ H_2$$

Destruction of Organic Compounds

$$Cl_2C = CHCl + OH\bullet \longrightarrow Cl_2\dot{C} - \underset{}{\overset{OH}{\overset{|}{C}}}HCl$$
$$Cl_2\dot{C} - CHCl(OH) + (O_2,\ H_2O_2,\ \ldots) \longrightarrow \longrightarrow CO_2 + HCl + H_2O$$

AG123-G0696103

Nonproductive Radical Reactions

$$TiO_2^- + OH\cdot + H^+ \longrightarrow TiO_2 + H_2O$$

$$2\ OH\cdot \longrightarrow H_2O_2$$

$$2\ HO_2\cdot \longrightarrow H_2O_2 + O_2$$

$$HO_2\cdot + OH\cdot \longrightarrow H_2O + O_2$$

$$H_2O_2 + OH\cdot \longrightarrow H_2O + HO_2\cdot$$

$$HCO_3^- + OH\cdot \longrightarrow \cdot CO_3^- + H_2O$$

$$M^{+3} \underset{OH\cdot}{\overset{TiO_2^-}{\rightleftharpoons}} M^{+2}$$

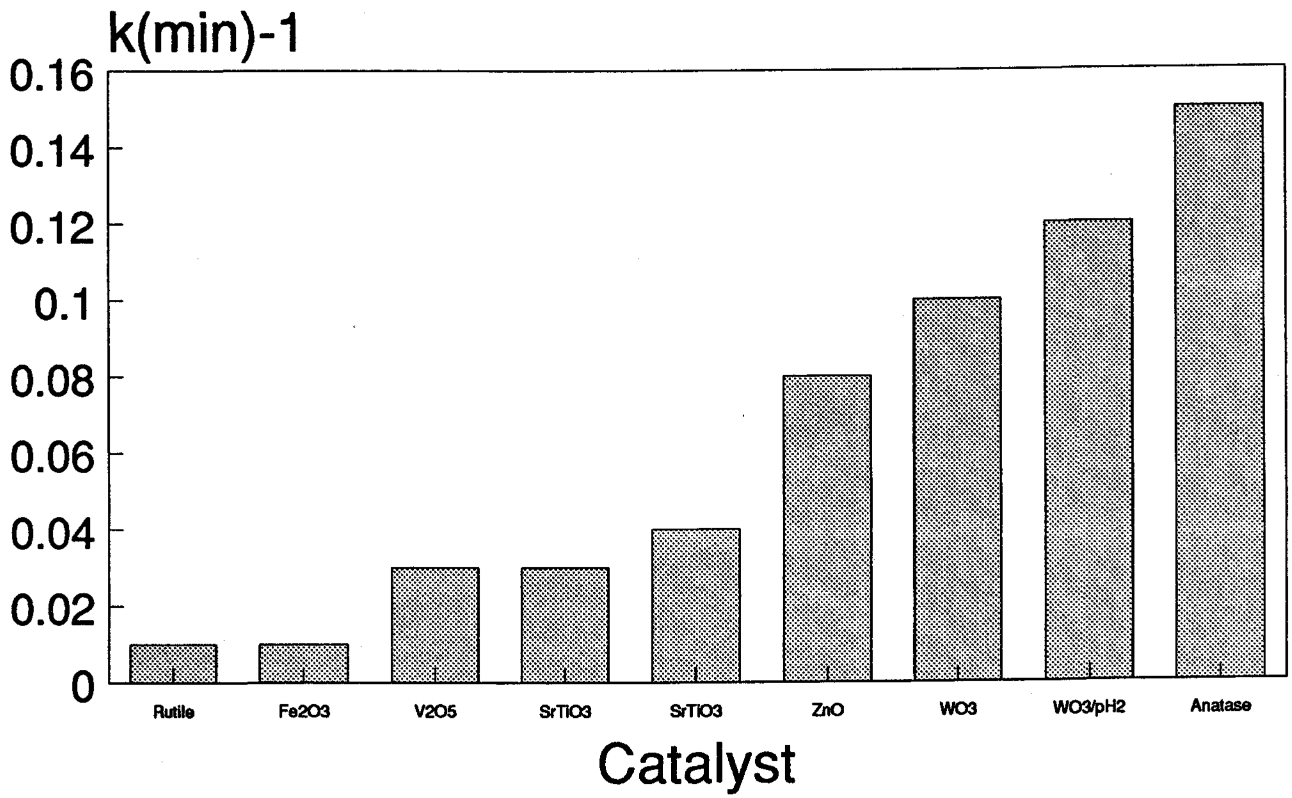
AG123-G0696104

RESULTS

- Activity of different semiconductors
- Activity of different forms of titanium dioxide
- Dependence of destruction rate on light flux
- Effect of bicarbonate ion on destruction rate

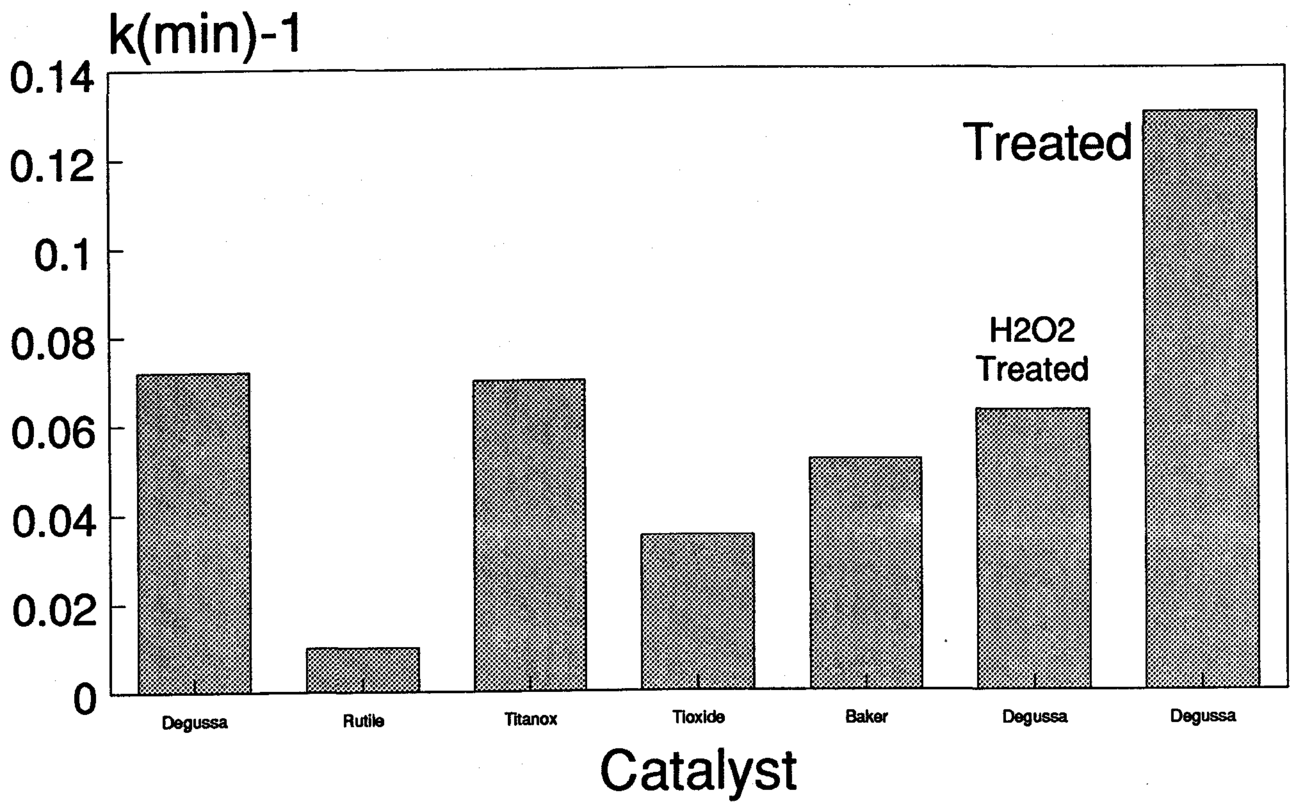
dmb-104

TCE PHOTOCATALYTIC DECOMPOSITION
0.1% Catalyst

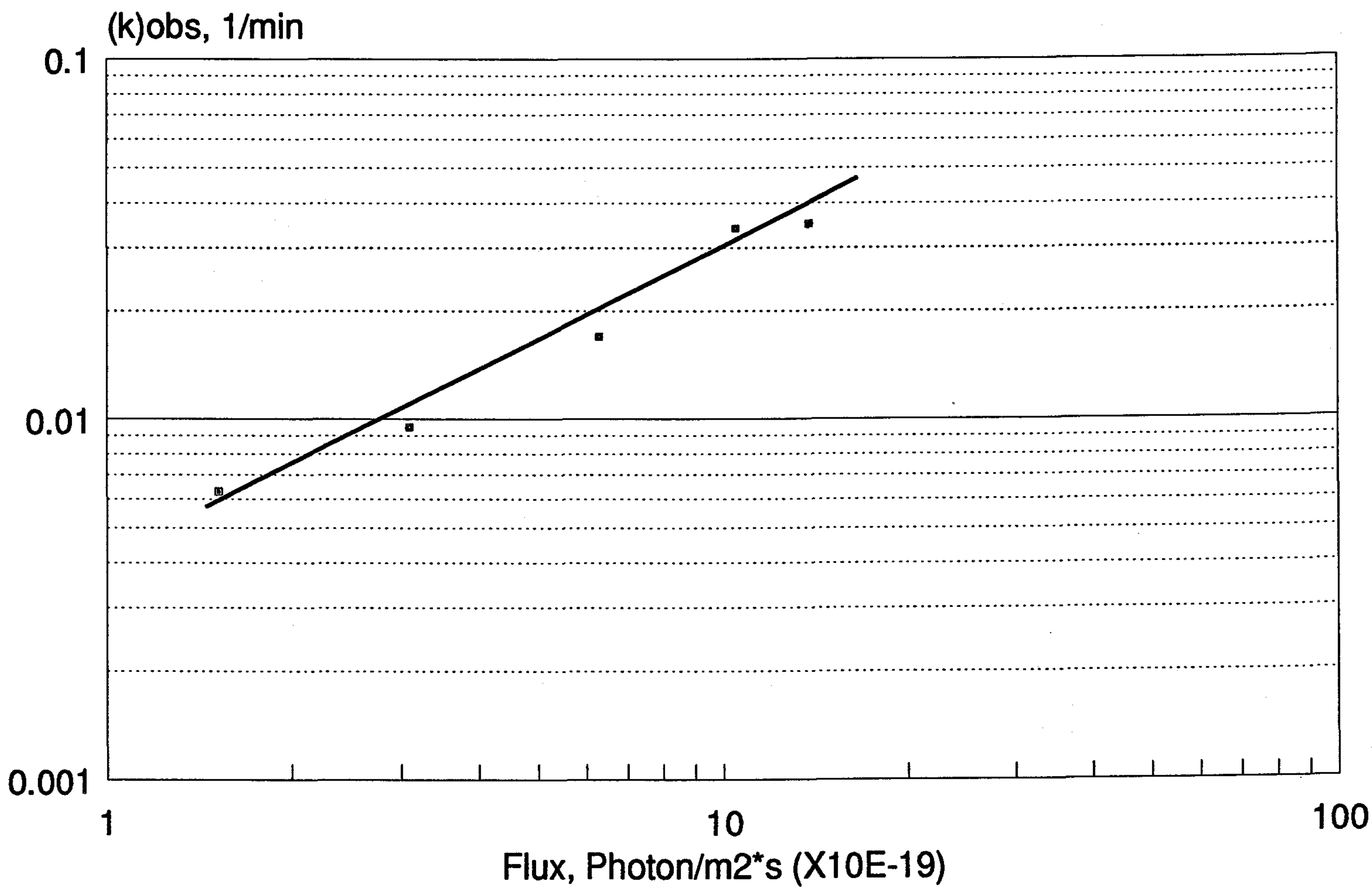


SERI

PHOTOCATALYTIC TCE DECOMPOSITION
0.1 wt% TiO2 Powders

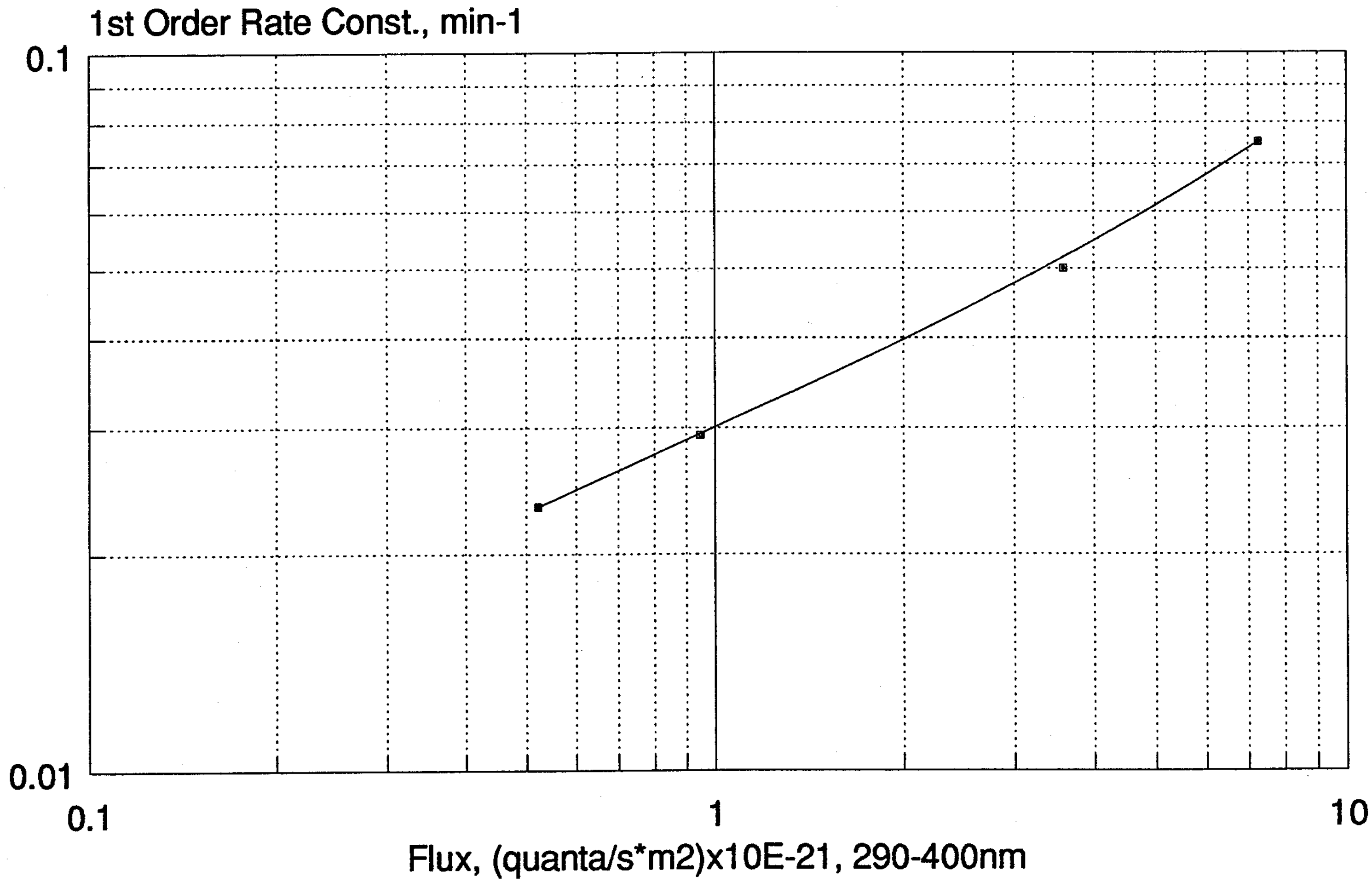


Flux Dependence of TCE Destruction Rate



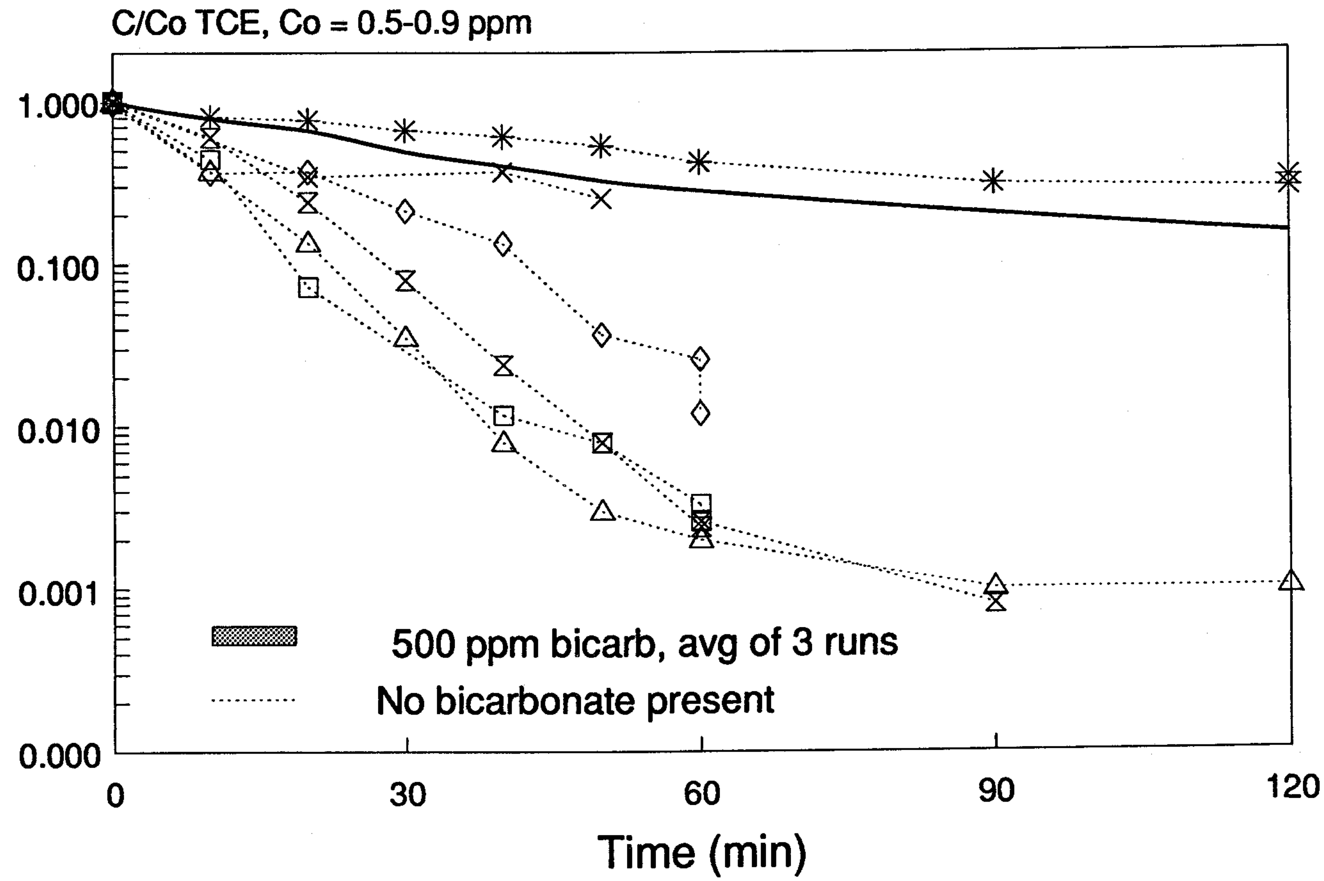
dmb-59

Flux Dependence of Formate Destruction Rate



dmb-60

TCE/BICARBONATE EXPERIMENTS
0.1 wt% TiO2, Initial pH=7.0 + 0.2



CST/qqq.cht

SERI

PLANNED WORK

- Expand treatability studies on groundwater and process waste streams
- Improve activity of photocatalysts
- Identify intermediates and by-products, if any, that are formed during the destruction process

dmb-106

CONCLUSIONS

- The general features of the chemical mechanism for photocatalytic oxidation of organic compounds in water are known

- Key water quality factors which impact the process have been identified

- For typical hazardous organic compounds the destruction rate depends on the square root of light flux

dmb-105

SOLTECH91

Solar Industrial Program/Solar Thermal Electric Program Symposia

- Symposium No: 4
- Symposium Title: Solar Thermal Electric Systems
- Date: Thursday, March 28, 1991 • Time: 8:30 - Noon
- Chairperson(s): David Kearney (LUZ Engineering Company)

Time Slots	Presentations	Proposed Speakers (Name/Affiliation)
8:30 - 8:40	Introduction	Session Chairperson
8:40 - 9:00	Update on the CPG Dish/Stirling System Development	Jerome Davis (Cummins)
9:00 - 9:20	The LUZ SEGS Plants: Current Status and Future Plans	David Kearney (LUZ)
9:20 - 9:40	Development of an Industry Consortium to Build a Central Receiver Power Plant	Greg Kolb (Sandia)
9:40 - 10:00	Externalities in Electric Generation Planning and Development -- A California Status Report	James Chavez/Daniel Alpert Alec Jenkins (California Energy Commission)
10:00 - 10:20	BREAK	
10:20 - 10:40	The Hawaii Experience: Problems with Geothermal Energy Development and the Growing Opportunities for Solar Thermal Technology	Andrew Trenka (Pacific International Center for High Technology Development)

SOLTECH91

Solar Industrial Program/Solar Thermal Electric Program Symposia

- Symposium No: 4 (Concluded)
- Symposium Title: Solar Thermal Electric Systems
- Date: Thursday, March 28, 1991 • Time: 8:30 a.m. - Noon
- Chairperson(s): David Kearney (LUZ Engineering Company)

Time Slots	Presentations	Proposed Speakers (Name/Affiliation)
10:40 - 11:00	Opportunities for Renewable Energy Systems on Military Bases	Gerald G. Leigh (University of New Mexico)
11:00 - 11:20	How Solar Electric Technology May Help Alleviate Severe Electricity Shortages in the Dominican Republic	Ellis Perez (Solar Uno)
11:20 - 11:40	Opportunities for Solar Thermal Electric Technology in Nevada	Commissioner Rose McKinney-James (Public Service Commission of Nevada)
11:40 - Noon	PV Control Receivers: Their Potential Role in Solar-Electric Generation	Richard Swanson (SunPower)

SOLTECH '91

UPDATE ON THE CPG

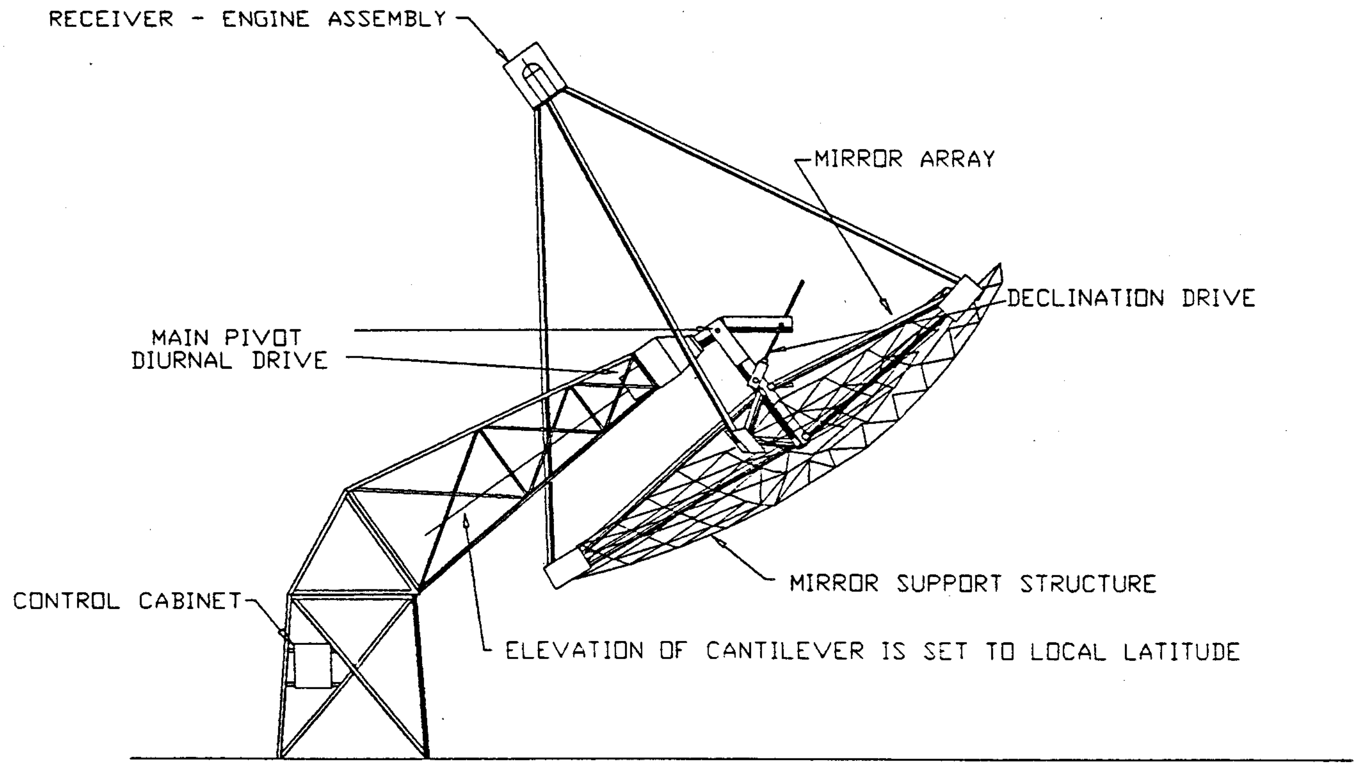
DISH/STIRLING SYSTEM DEVELOPMENT

JEROME DAVIS

PRESIDENT

CUMMINS POWER GENERATION

JD/3/28/91



CUMMINS POWER GENERATION SYSTEM DIAGRAM

SYSTEM DESCRIPTION

The current CPG Solar Dish/Stirling System consists of the following components:

- Multi-Facets, Focusing Solar Concentrator
- Heat Pipe Receiver
- Free Piston Stirling Engines with Linear Alternators
- Total Control System

    Solar Tracking

    Receiver Temperature Control

    Emergency Shut-Down

    Both Grid Connected and Stand Alone System

SYSTEM CHARACTERISTICS

- DIRECT CONVERSION OF SOLAR THERMAL ENERGY TO ELECTRICITY
- HIGH CONVERSION EFFICIENCY
  . NET CONVERSION EFFICIENCY (NET ELECTRIC OUT/SOLAR INPUT): 30%*
- HYBRID SYSTEM (SOLAR/GAS BURNER) POSSIBLE
- IMMEDIATE START-UP IN THE MORNING
  . NO WARM-UP OF WORKING FLUID REQUIRED
- LOW COST*
- HIGH RELIABILITY*
- LONG LIFE*
- LOW MAINTENANCE REQUIREMENT*

*: PRODUCTION VERSION

5 kW "PROOF OF CONCEPT" (PHASE I)

- IN OCTOBER, 1988, PUT "STAKE IN THE GROUND" -- INTEGRATED FREE PISTON DISH STIRLING SYSTEM ON TEST IN 1 YEAR (5 kW SYSTEM)

- ASSEMBLED TEAM
  - CPG -- SYSTEM INTEGRATION
  - CTC -- TECHNICAL AND MANUFACTURING SUPPORT
  - CEL -- ELECTRONICS
  - SUNPOWER -- FPSELA
  - LAJET ENERGY -- CONCENTRATOR
  - THERMACORE -- HEAT PIPE RECEIVER

- SANDIA ALSO ADVISED
- MET ONE YEAR TARGET. CONTINUED DEMONSTRATIONS IN 1990.
- ACCOMPLISHMENTS (REPORTED AT SOLTECH '90)
  - AUTOMATIC OPERATION (AUTO-START, EMERGENCY SHUTDOWN, AUTO-FOCUS)
  - SYSTEM CONTROLS
  - MATCHING OF CONCENTRATOR TO THE HEAT PIPE FLUX CAPABILITY

JD/3/28/91

ACCOMPLISHMENTS SINCE SOLTECH '90

- CPG CONTINUED 100% FUNDING OF 5 kW PROGRAM
- LEARNED SYSTEM INTEGRATION ISSUES AND SOLUTIONS FOUND
- REFINED MARKETING ANALYSIS
- REFINED MANUFACTURING ANALYSIS
- COMPONENTS DEVELOPMENT
  - FPSE
  - CONCENTRATOR
  - RECEIVER
  - INTGEGRATED CONTROLLER (CEL PRODUCT)

JD/3/28/91

COMPONENT DEVELOPMENT
(1990 - 1991)

FPSE

- 5 kW SOLAR FPSE DESIGN/MANUFACTURING COMPLETED
- TESTING & PERFORMANCE DEVELOPMENT STARTED

    - TARGET:
        - 5 kW NET OUTPUT
        - 32% ENGINE/ALTERNATOR EFFICIENCY

CONCENTRATOR

- NEW DRIVE MECHANISM
    - COST REDUCTION
    - STABLE OPERATION

- FEEL CONCENTRATOR IS A PRODUCT

CONTROLLER

- INTEGRATED CONTROLLER

RECEIVER

- SIMPLIFIED ARTERY NETWORK DESIGN
- SERI SUPPORTED ENDURANCE TEST STARTED
    - 100 HOURS AT 675°C OPERATING TEMPERATURE

JD/3/28/91

CPG DISH/STIRLING PROJECTS

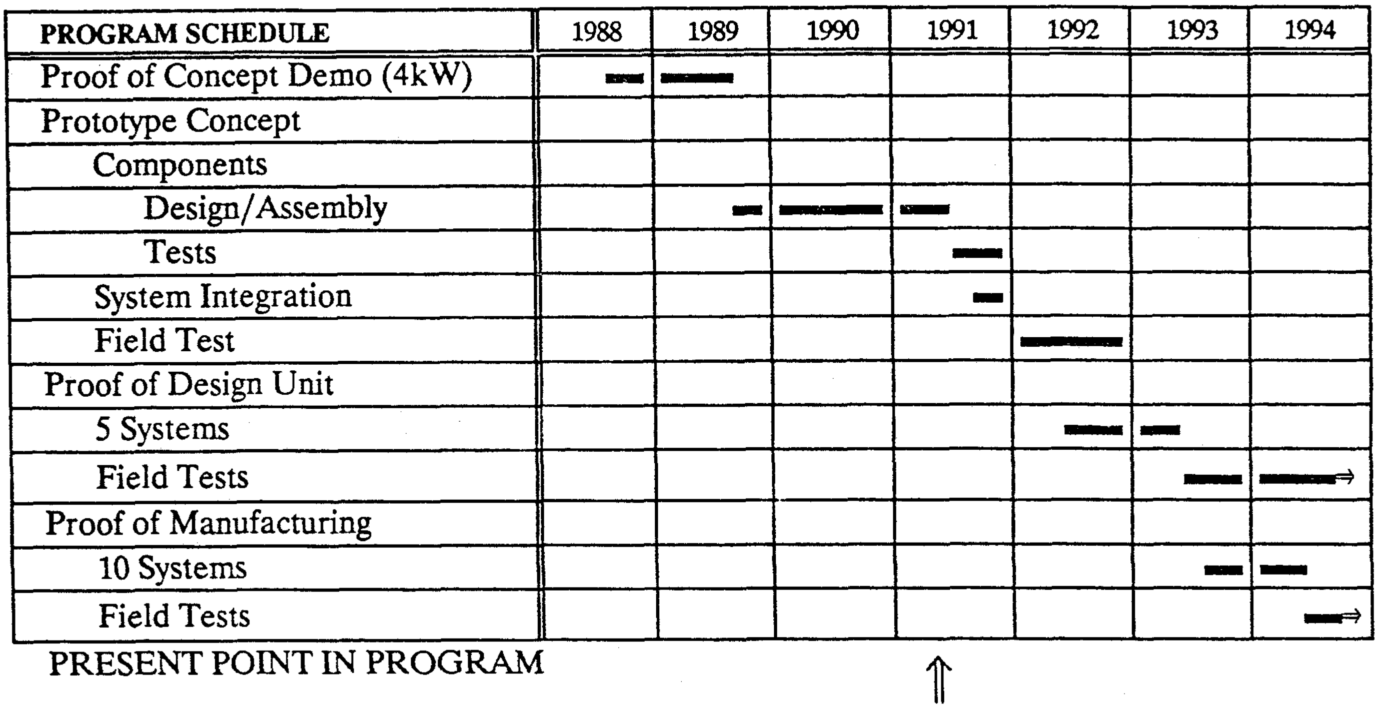
- 5 kW DISH/STIRLING SYSTEM PROJECT
  - REMOTE, STAND ALONE INTERNATIONAL
  - WATER PUMPING
- DOE/NASA 25 kW ADVANCED STIRLING CONVERSION SYSTEM (ASCS) PROJECT
  - INTERNATIONAL, DOMESTIC GRID CONNECTED
  - LARGER STAND ALONE APPLICATIONS

OBJECTIVE

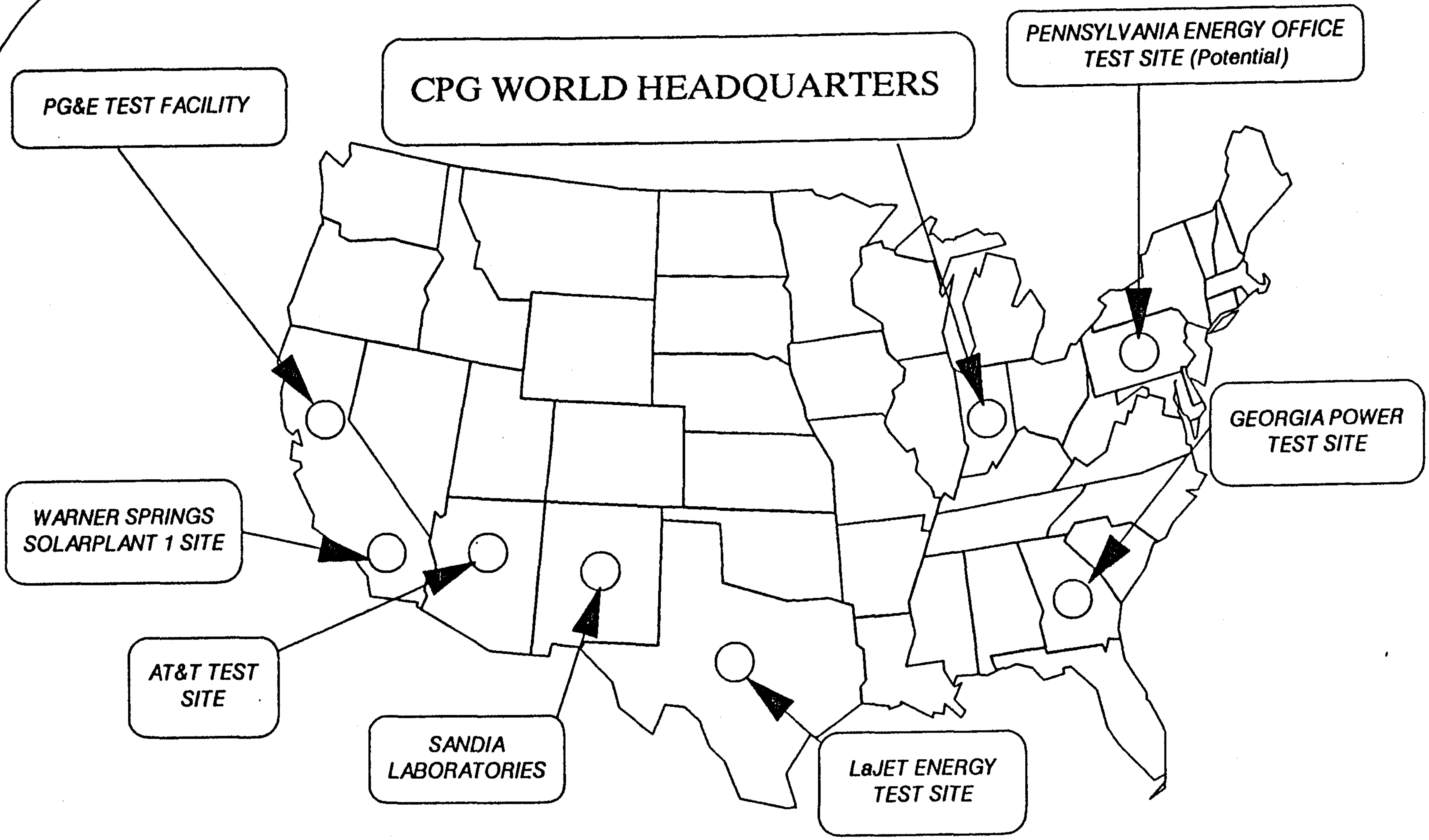
- COMMERCIALIZATION WITHIN THE NEXT FOUR YEARS

JD/3/28/91

CPG 5 kW DISH/STIRLING SYSTEM



LEGEND	
—	Activity
⇒	On-going Activity After End of Contract Period



CUMMINS POWER GENERATION
DISH/STIRLING JOINT VENTURE PROGRAM
DEVELOPMENT AND TEST FACILITIES

The LUZ SEGS Plants: Current Status & Future Plans

presented at:

SOLTECH 91

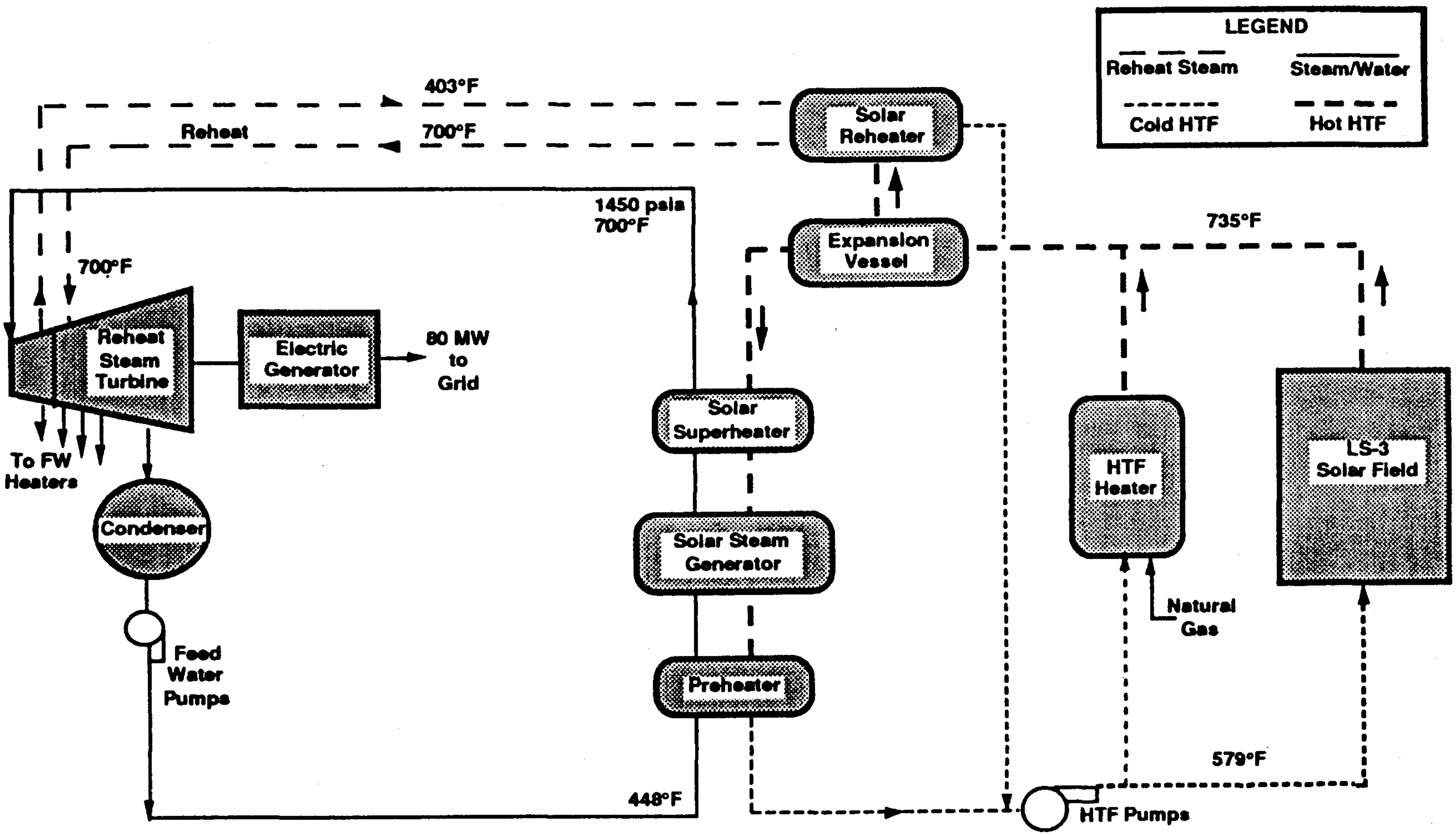
by

Dr. David Kearney, Vice President
Luz International Limited
924 Westwood Boulevard
Los Angeles, CA 90024

(213) 208-7444

March 28, 1991

SEGS Process Flow Diagram with LS-3 Collectors



Characteristics of SEGS I-IX

Plant	First Full Operating Year	Status	Turbine Capacity (MWe net)	Solar Field Temp (°F)	Solar Field Size (m2)	Turbine Cycle Efficiency Solar	Turbine Cycle Efficiency Boiler	Annual Output (MWh net)
I	1985	Operational	13.8	585	82,960	29.4	---	30,100
II	1986	Operational	30	600	188,987	29.4	37.3	80,500
III	1987	Operational	30	660	230,300	30.6	37.4	92,780
IV	1987	Operational	30	660	230,300	30.6	37.4	92,780
V	1988	Operational	30	660	233,120	30.6	37.4	91,820
VI	1989	Operational	30	735	188,000	37.5	39.5	90,850
VII	1989	Operational	30	735	194,280	37.5	39.5	92,646
VIII	1990	Operational	80	735	464,340	37.6	37.6	252,750
IX	1991	Operational	80	735	483,960	37.6	37.6	256,124

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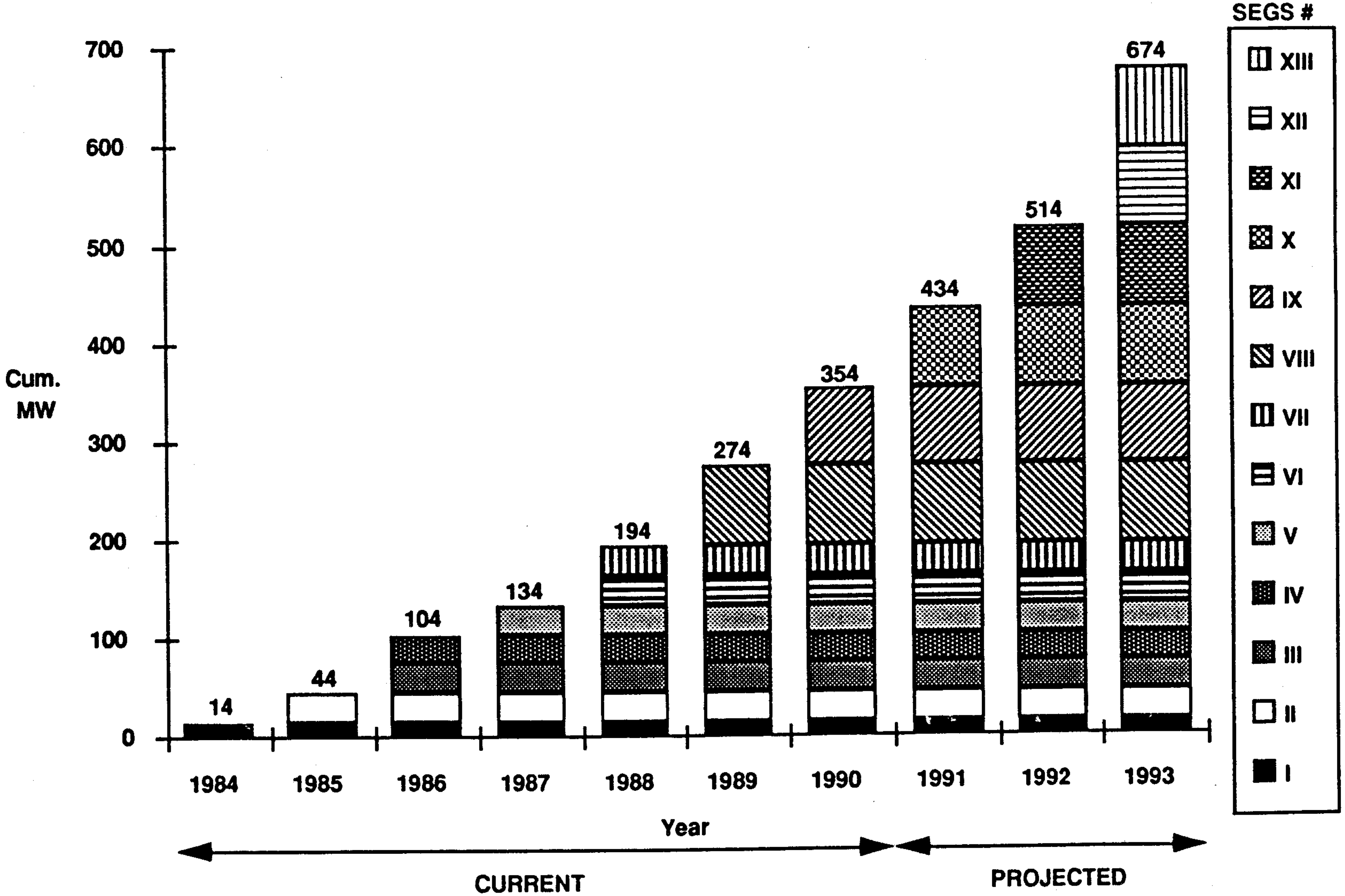
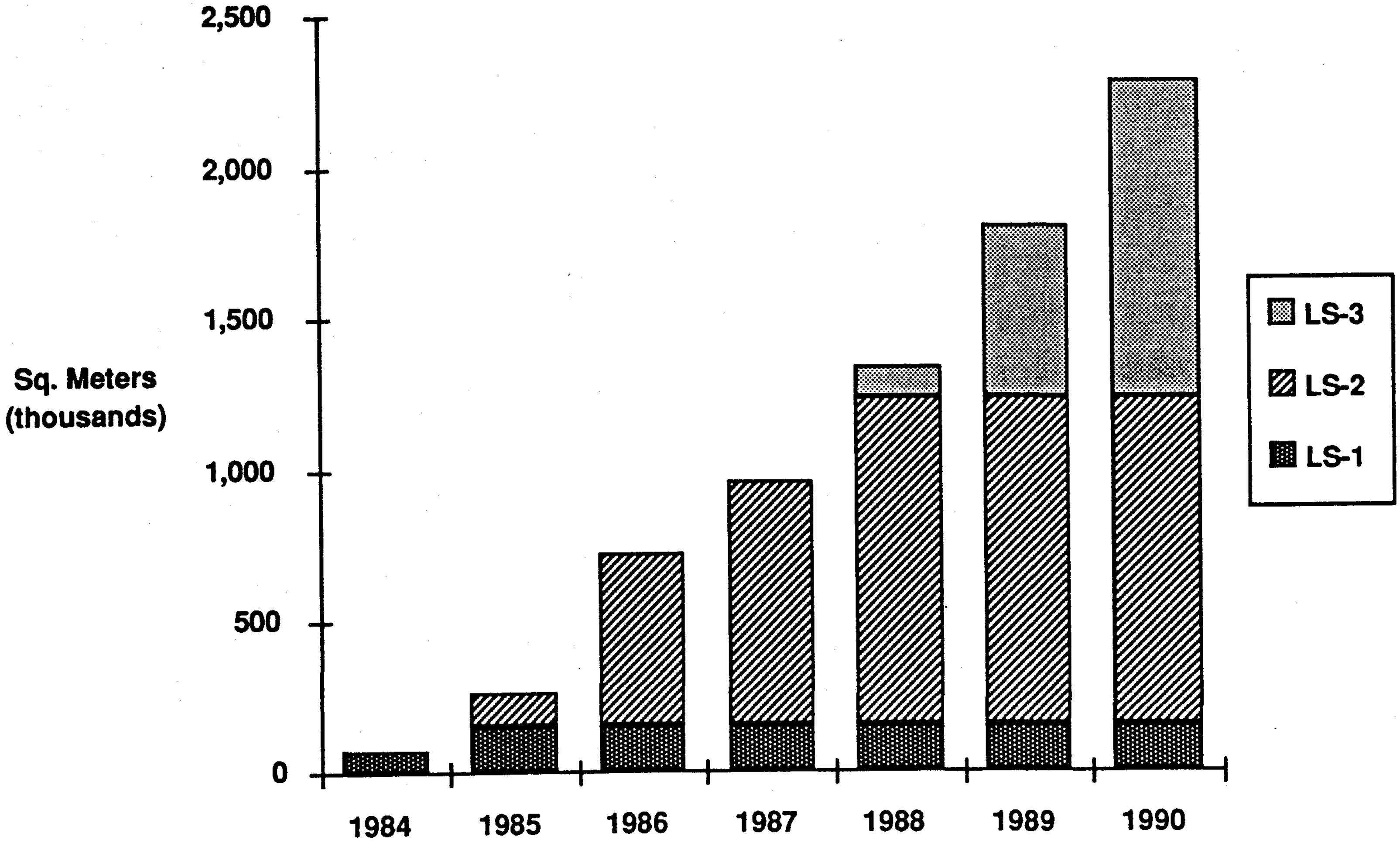
Current & Projected LUZ Solar Capacity



Note: Current capacity is on-line, projected capacity represents signed contracts.

Luz Solar Collector History
Cumulative Installed Area



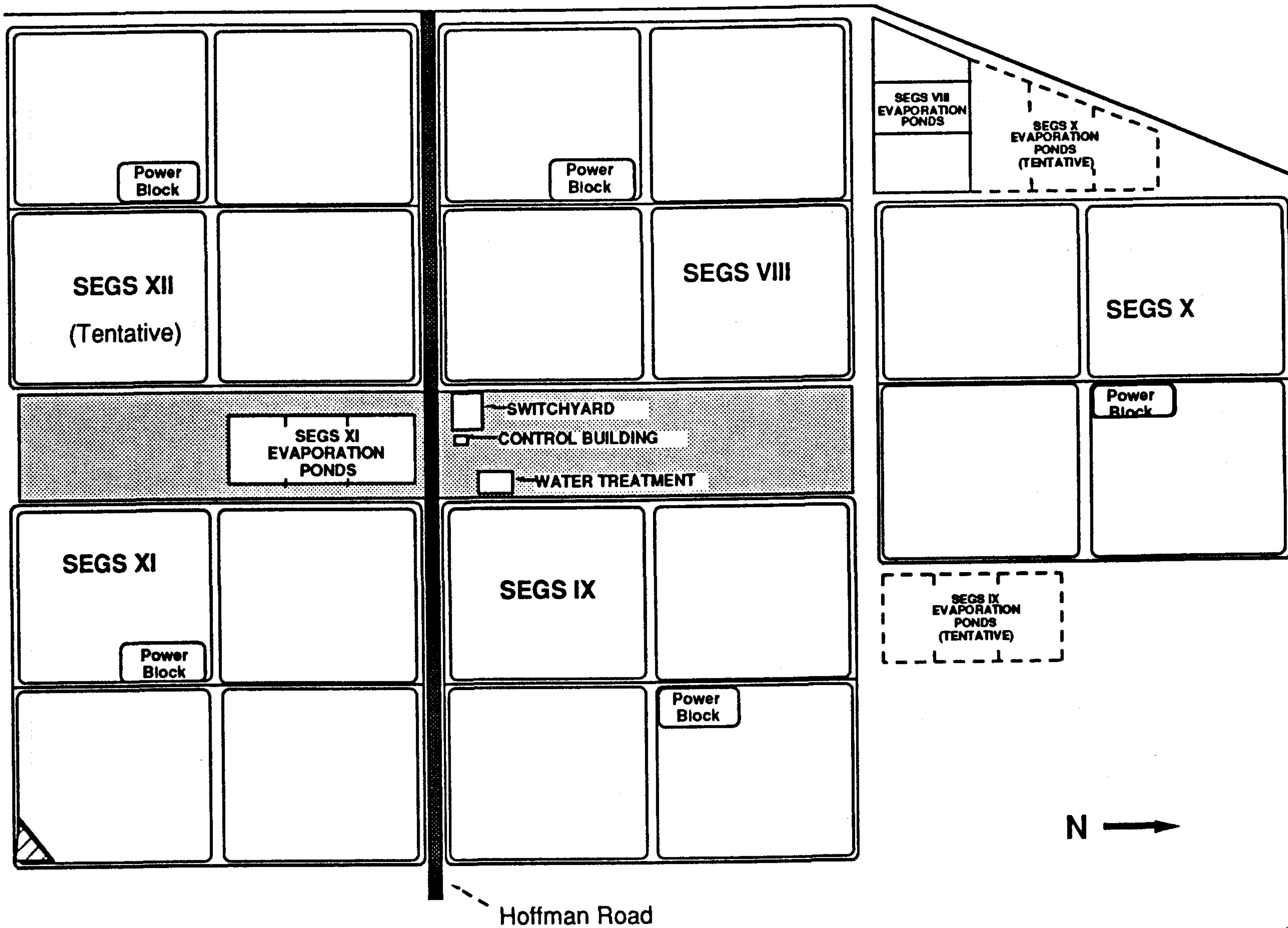
Historical Solar Project Development

	Capacity Contract Type	Collector Type & Fld. Size	S.F. Temp.	Electrical Conversion Efficiency	Introduction of New Technology
SEGS I 1984	13.8 MW Special Contract	LS-1 83,000 sqm	585 F	31.5%	First LUZ collectors Solar must have independent superheater Storage 3 hours oil
SEGS II 1985	30 MW Special Contract	LS-1/LS-2 185,000 sqm	630 F	29.3%	Second generation LUZ collector double in aperture - Generation of electricity on solar only - Back-up boiler system
SEGS III & IV 1986	30 MW S.O. 4	LS-2 230,000 sqm	660 F	30.6%	Mature LS-2 collectors LUZ black chrome coating High temp. heat transfer fluid
SEGS V 1987	30 MW S.O. 4	LS-2 230,000 sqm	660 F	30.6%	
SEGS VI 1988	30 MW S.O. 4	LS-2 190,000 sqm	735 F	36.7%	Heat collectors sputtered coating for high temp. Reheat cycle (increasing cycle efficiency by 20%)
SEGS VII 1988	30 MW S.O. 4	LS-2/LS-3 190,000 sqm	735 F	36.7%	Third generation collectors trusses double in size
SEGS VIII 1989	30 MW S.O. 2	LS-3 465,000 sqm (30 MW equiv. to 185,000 sqm)	735 F	38%	80 MW size Oil heaters back up system Mature LS-3 collector and sputtered heat collector

Historical Solar Project Development (Continued)

	Capacity Contract Type	Collector Type & Fld. Size	S.F. Temp.	Electrical Conversion Efficiency	Introduction of New Technology
SEGS IX-XII 1990-1993	80 MW S.O.2	LS-3 485,000 sqm	735 F	38%	
SEGS 94 (Goals)	120-200 MW (compatible with $20/barrel)	LS-4 600,000-1,000,000 sqm	790 F	41%	Direct Steam Generation at solar field Fourth generation new generating collectors Conventional high efficiency power generation

Harper Lake Plot Plan

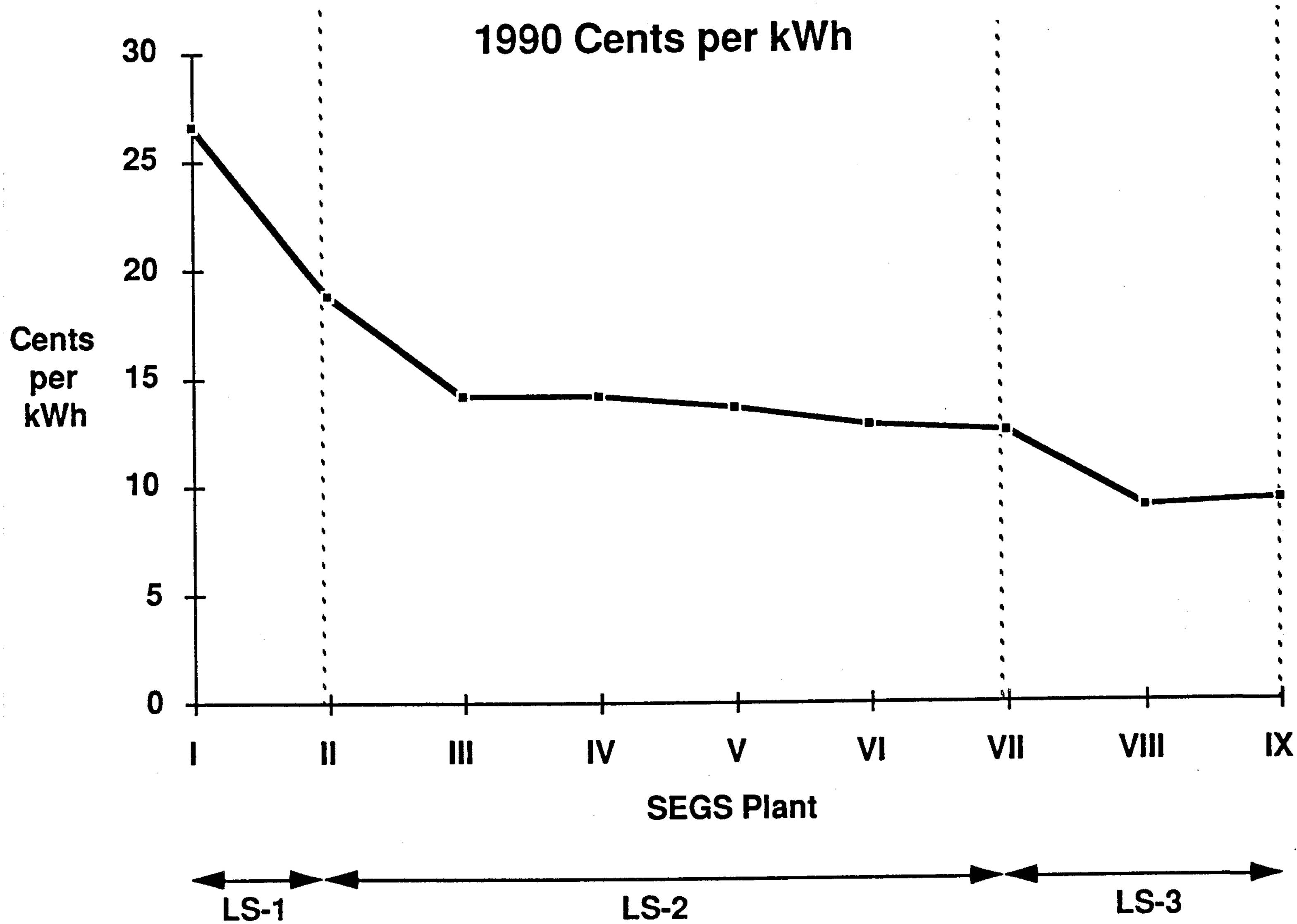


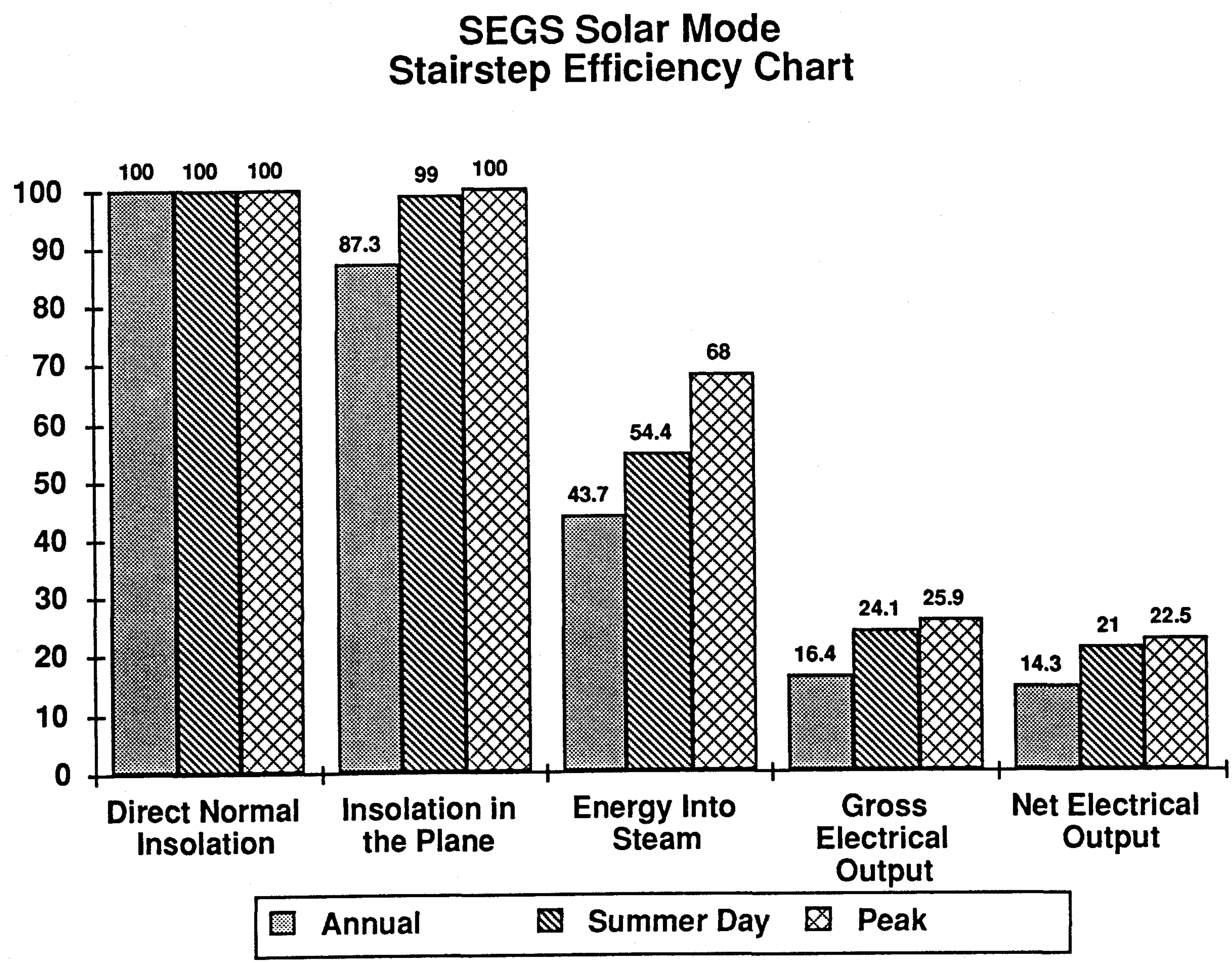
LUZ International Limited

LUZ Solar Electric Generating Systems / Cost Reduction Trend

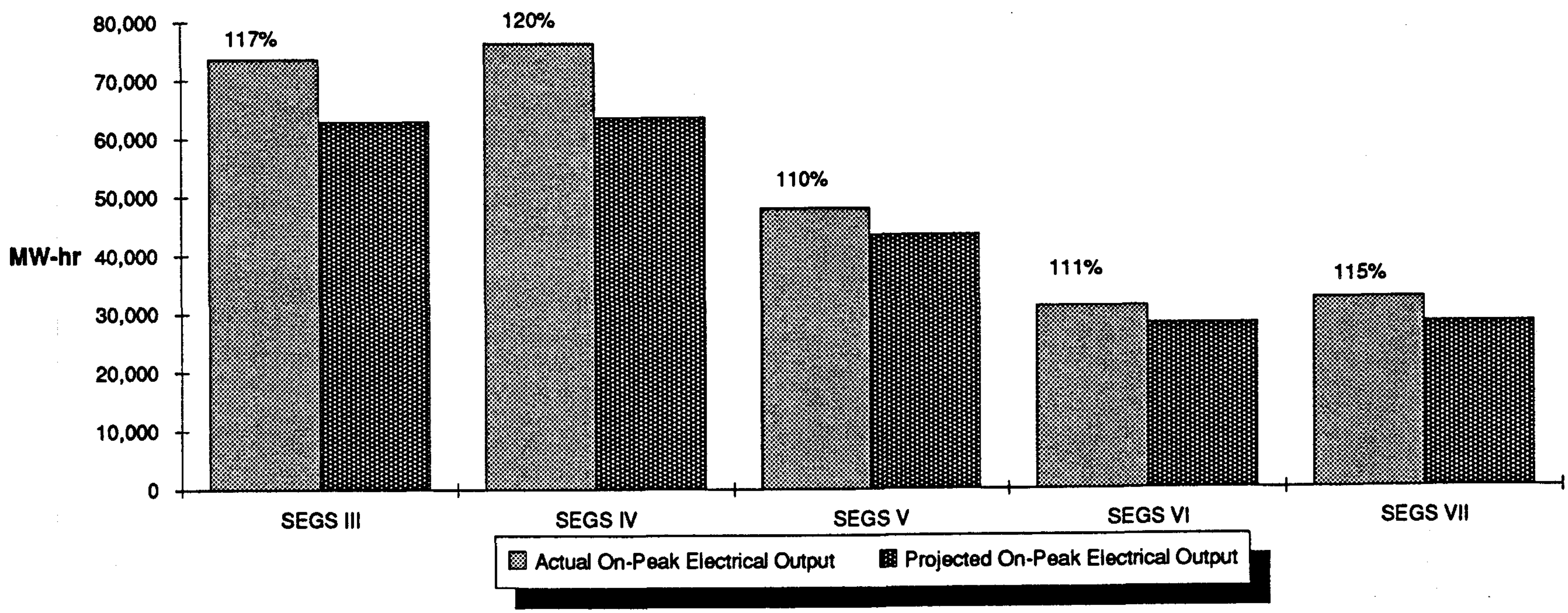
	SEGS I	SEGS VI	SEGS VIII	SEGS 94
MW Capacity	13.8	30.0	80.0	200.0
Reflecting Surface (Square Meters)	82,960	188,000	464,000	1,000,000
Total MWhe per Year	30,000	91,000	254,000	650,000
Project Price ($ million)	62.0	116.0	231.0	398.0
Price per kW Installed	$4,500	$3,860	$2,875	$1,991

Levelized Cost of Power From SEGS

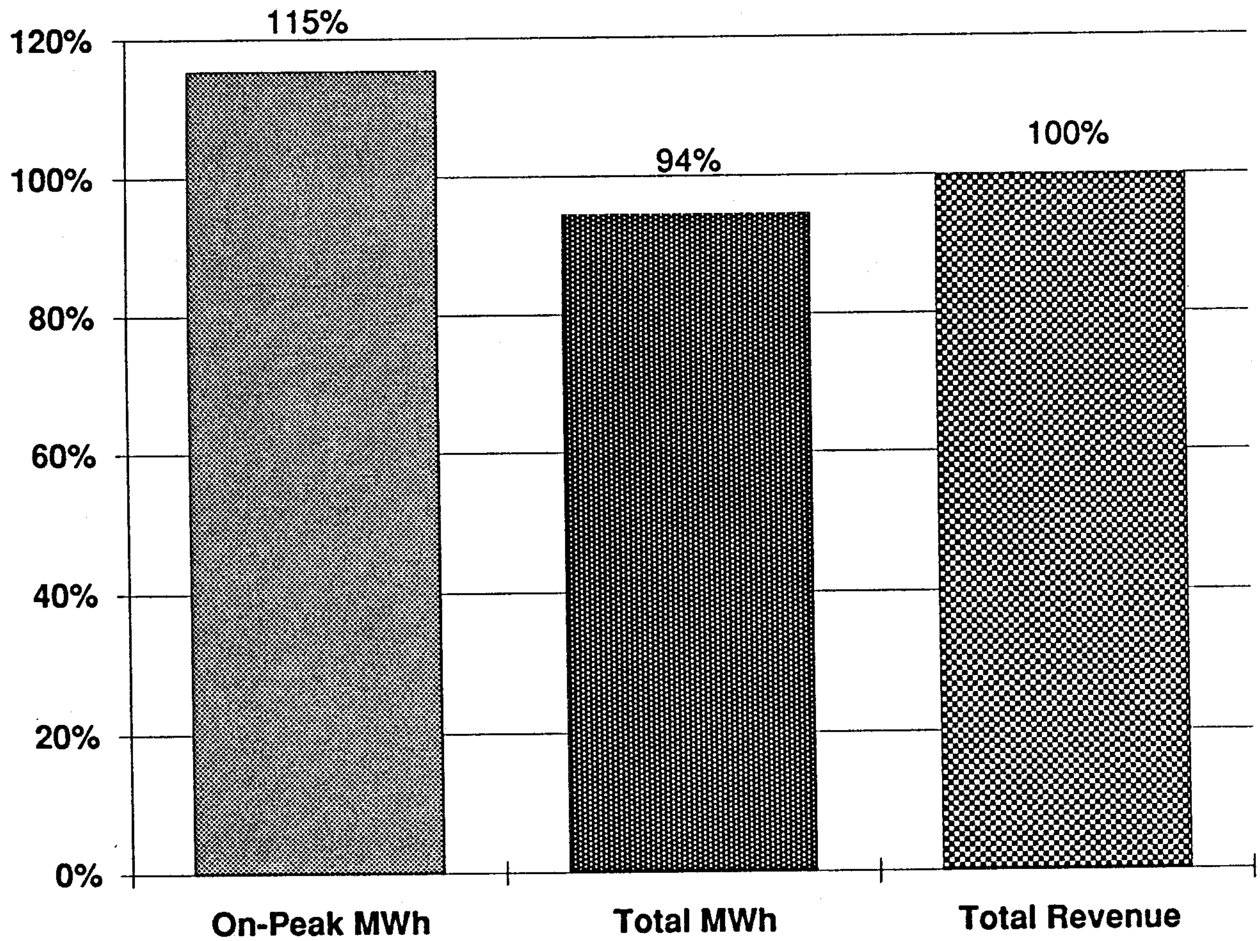



SEGS Solar Mode
Stairstep Efficiency Chart
100 100 100
99 100
87.3
68
54.4
43.7
24.1 25.9
16.4
21 22.5
14.3
100
90
80
70
60
50
40
30
20
10
0
Direct Normal Insolation
Insolation in the Plane
Energy Into Steam
Gross Electrical Output
Net Electrical Output
Annual
Summer Day
Peak

SEGS III - VII
1987-1990 On-Peak Electrical Output
Actuals vs. Original Projections

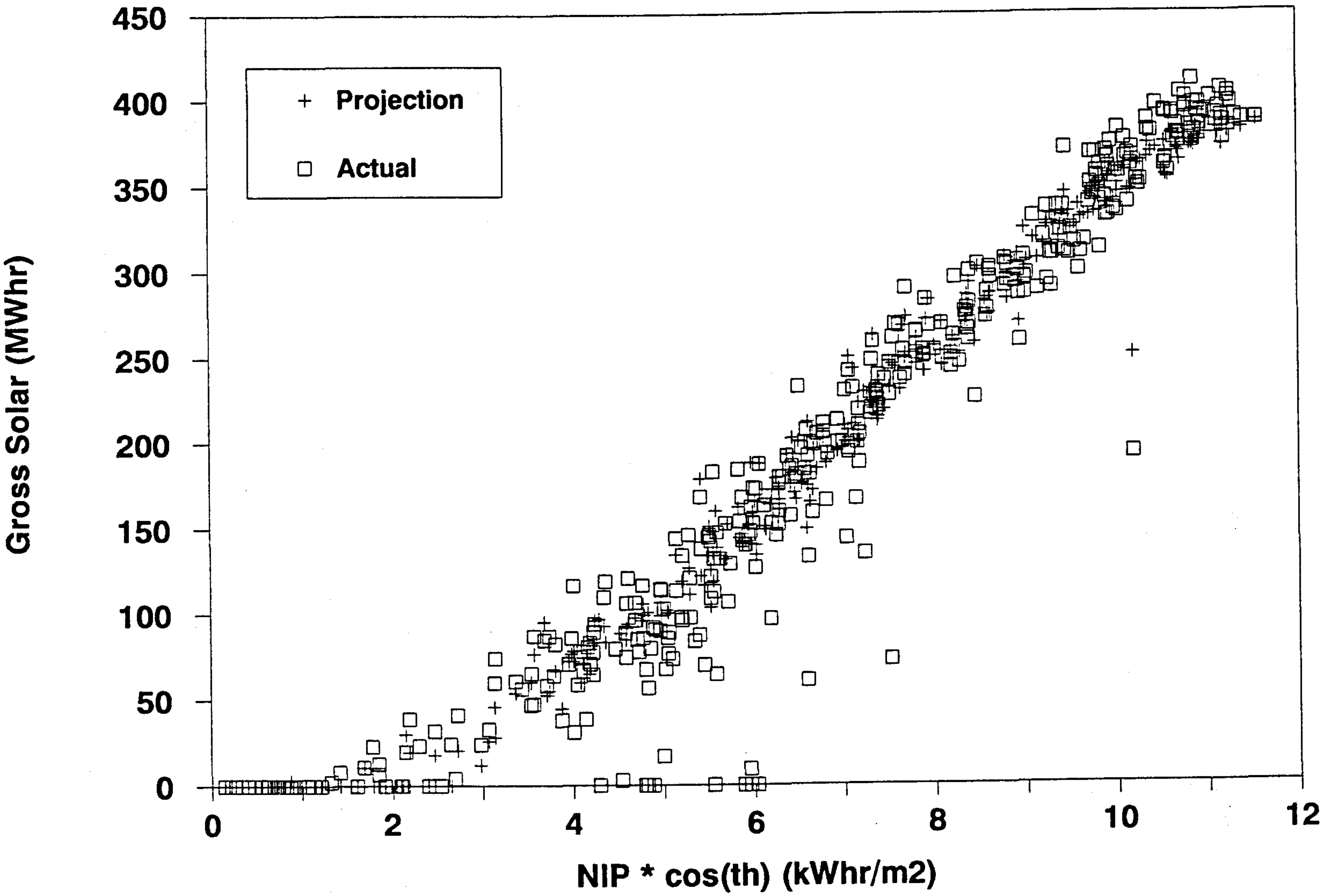


1987-1990
Cumulative SEGS Performance at Kramer Junction
As a Percentage of Originally Projected Performance



SEGS IV 1990 Solar Output vs NIP

Actual and Projected Gross Electricity



LUZ Development
Goals and Objectives

<u>SEGS Technology Today</u>:

- 354 MW Installed with ~ 2,100,000 sq.m Collectors

- SEGS VIII Investment Costs ~ $3,000 / KW

<u>SEGS Technology 1994 and Beyond in the U.S.</u>:

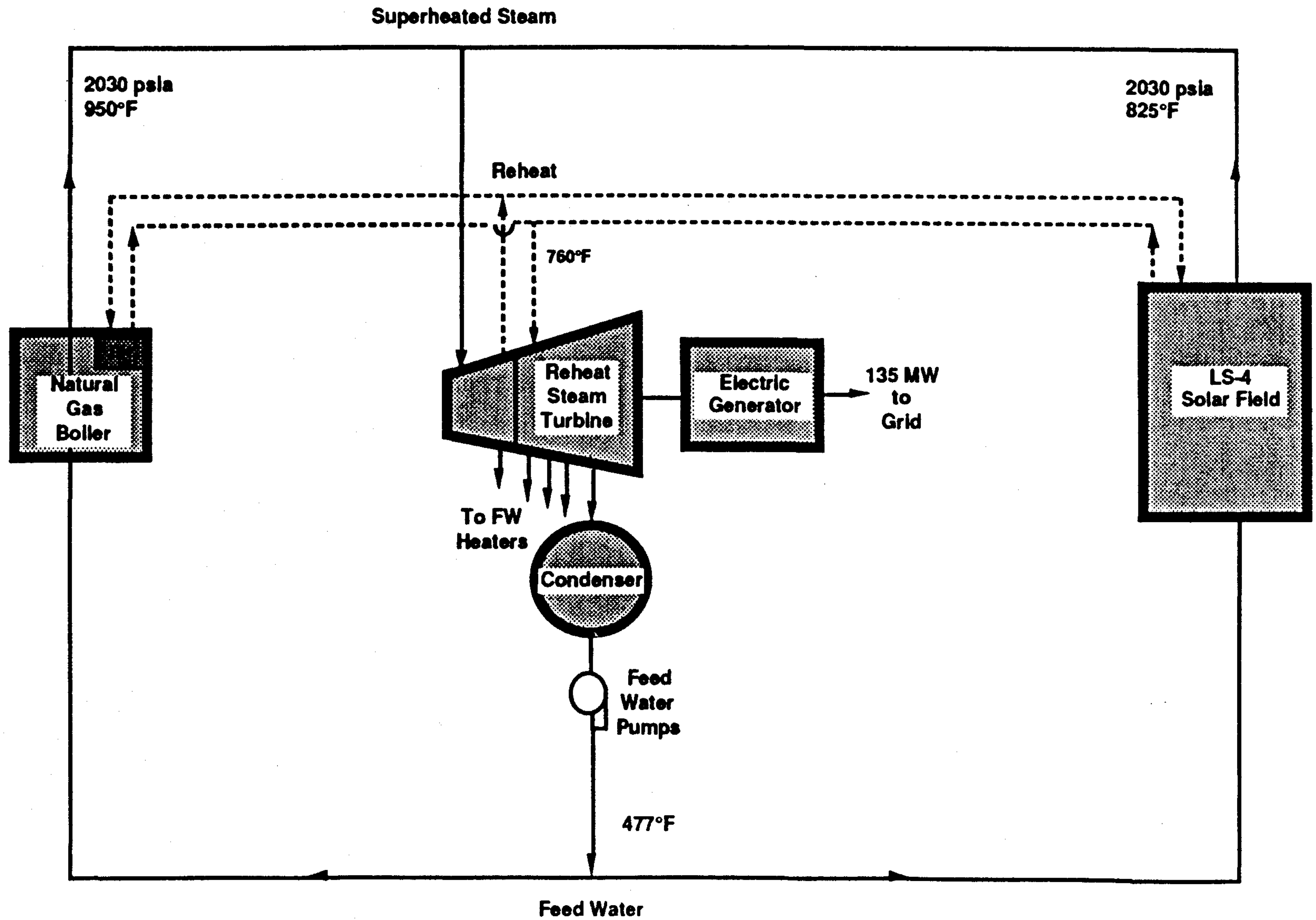
- 1000-1500 MW Installed with 5-7 Million sq. m Collectors

- SEGS 1994 Investment Costs ~ $2,000 / KW

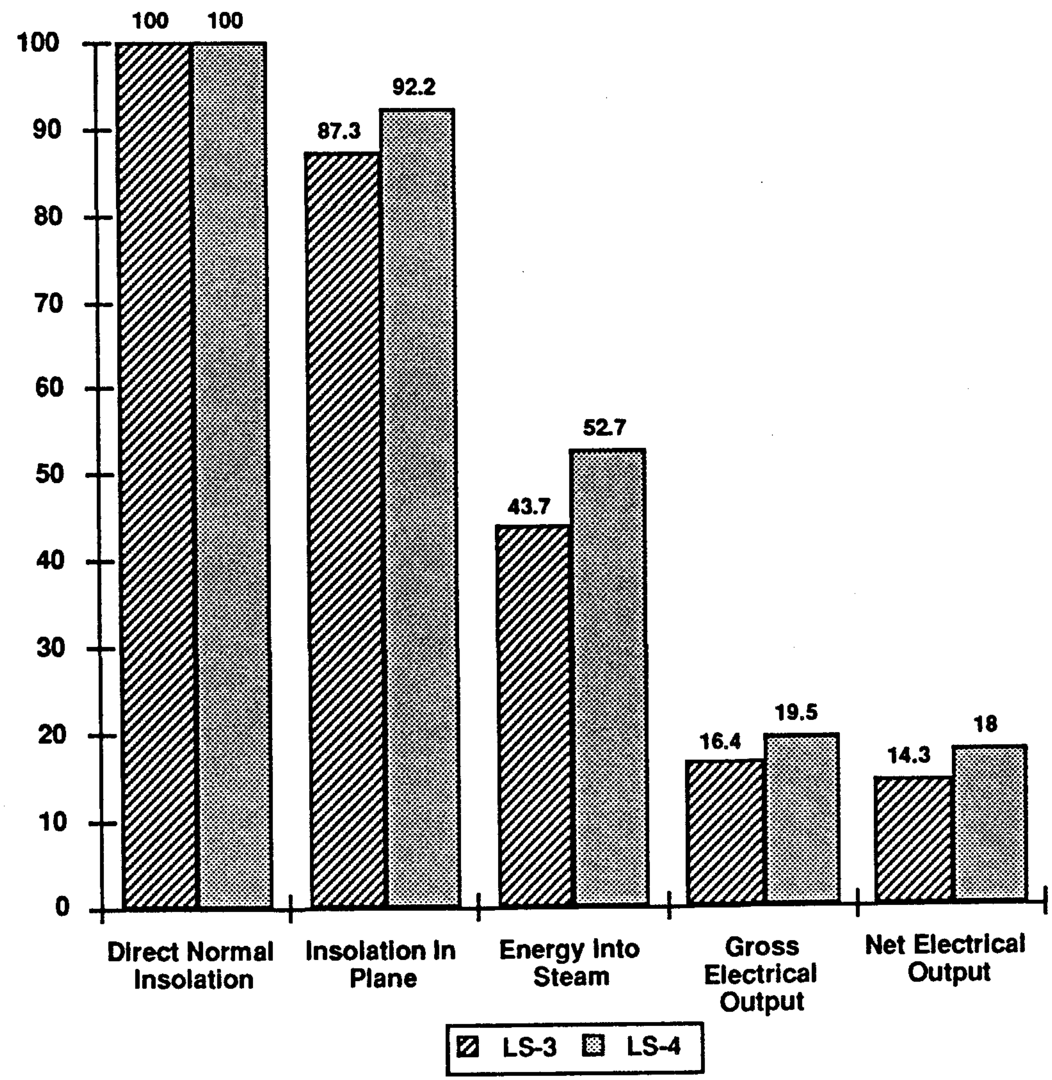
LS- 4 ADVANCED TROUGH CONCEPT

- **ADVANCED CYCLE**
  - Integrated GT Combined Cycle
  - Improved Steam Cycle
- **ADVANCED COLLECTOR**
  - Tilt-8 Degrees
  - Dimensional Changes
  - Advanced Materials
- **ADVANCED PROCESS**
  - Direct Steam Generation
- **OTHER IMPROVEMENTS**
  - Absorptivity-0.98
  - Emissivity-0.15
  - Anti-Reflective Coating
  - Solar Field Controls

SEGS Process Flow Diagram With Direct Steam Generation



Comparison of LS-3 and LS-4 Annual Solar Mode Stairstep Efficiency for SEGS Plants



LUZ International Limited

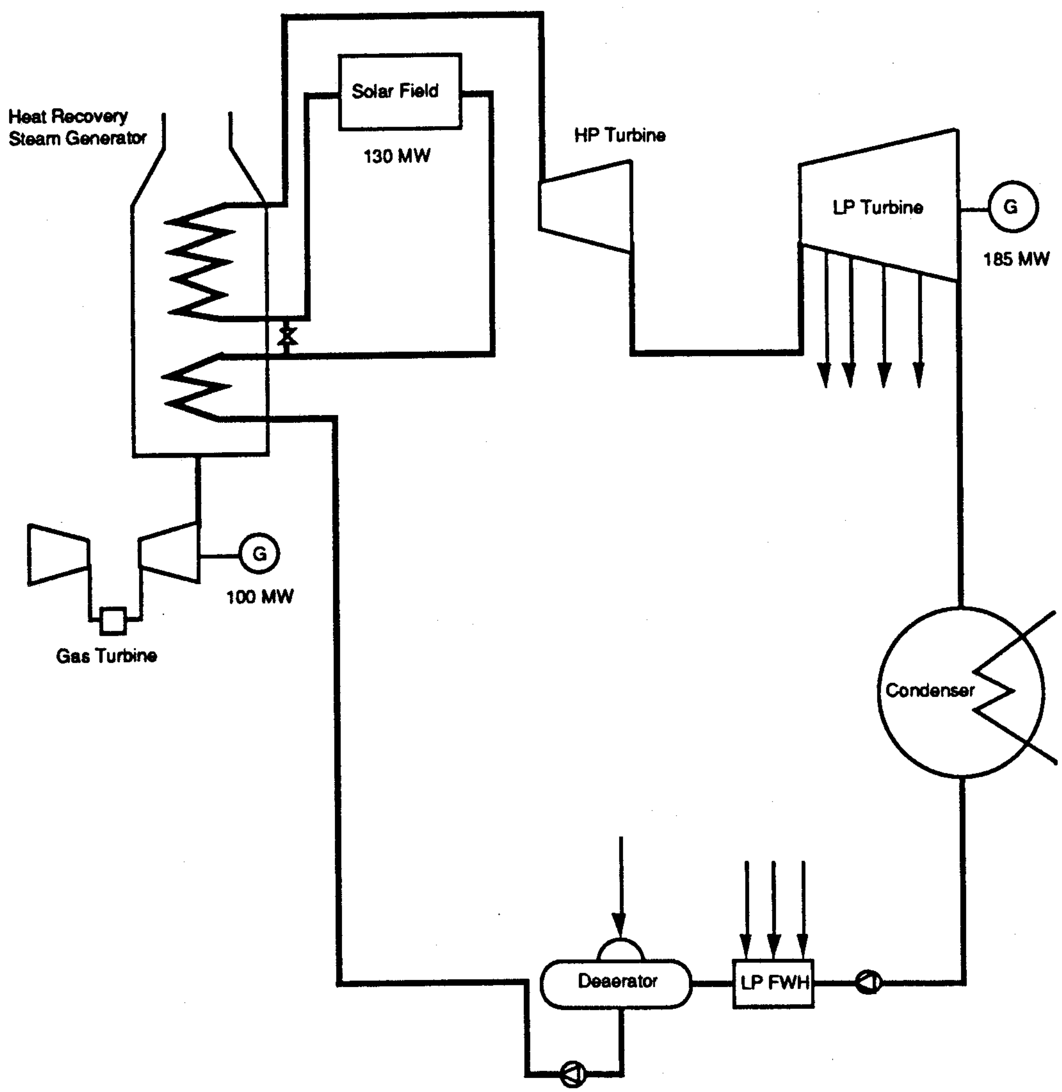
The SEGS/Combined Cycle Concept

- Add a gas turbine and heat recovery unit to a SEGS solar field to create a combined cycle/solar hybrid.
- Normally, the gas turbine is on when the plant is operating, although "pure" solar operation is possible.
  - The solar field is smaller than a SEGS plant of equal power.
  - The steam turbine is fed by the solar field and the heat recovery unit.
- An auxiliary boiler will replace the solar field energy to allow full output without sun.

Advantages of SEGS/Combined Cycle

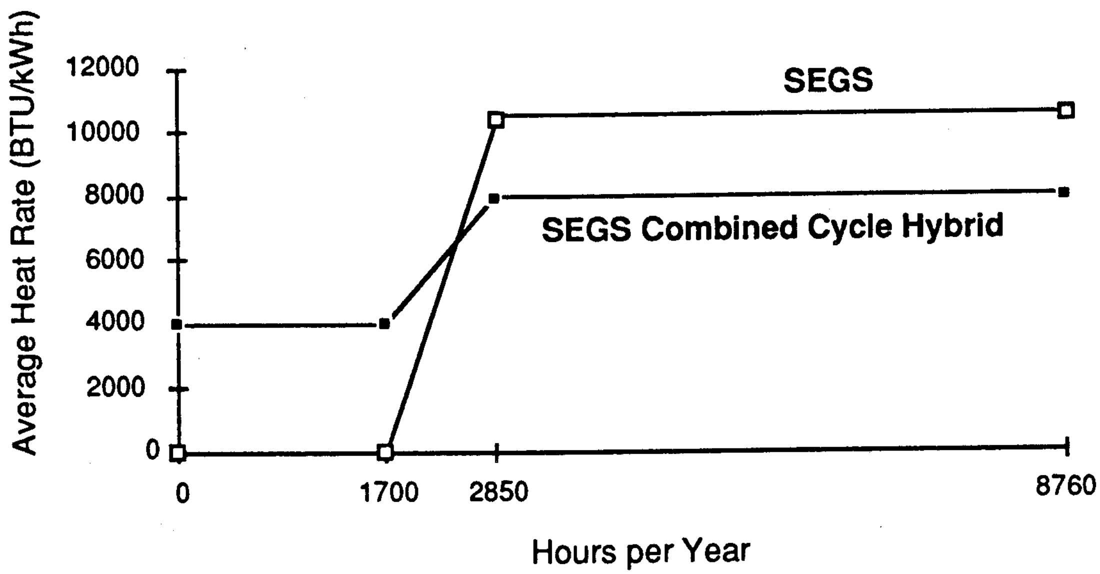
- Thermodynamic synergy boosts efficiency.
- Increased efficiency in fossil mode allows higher capacity factor operation.
- Lower capital cost than solar, lower fuel cost than conventional combined cycle.

SEGS/Combined Cycle Hybrid Schematic Diagram



SEGS/Combined Cycle Hybrid Performance Summary

- LUZ has explored single Hybrid units up to 285 MW.
- The graph shows heat rate (HHV) as a function of capacity factor for a 135 MW LS-4 Hybrid plant located in Southern Nevada.



Comparison of SEGS and Hybrid Designs

- Comparison of 135 MW plants
- Both options wet-cooled

	SEGS	Hybrid
Capacity (MW)	135	135
Solar Field Size (sq M)	652,280	372,230
Solar Field Capacity (MW)	135	92
Solar Field Annual Output (MWh)	321,975	213,458
Gas Turbine Output (MW)	NA	43
Full Solar Heat Rate (BTU/kWh)	0	4,022
Full Fossil Heat Rate (BTU/kWh)	10,500	8,800

Note that we have been able to improve the SEGS heat rate relative to that quoted in our original estimates.

Development of an Industry Consortium
to Build a
Central Receiver Power Plant

by
Gregory J. Kolb
James M. Chavez
Daniel J. Alpert

Sandia National Laboratories
Albuquerque, New Mexico

For 15 years, the Department of Energy has worked with industry, both utilities and vendors, to develop the technology of solar central receiver power plants. In this type of power plant, sunlight is concentrated by a field of sun-tracking mirrors onto a centrally located receiver on top of a tower. The solar energy is collected by the receiver in the form of a heated fluid, which is used to generate steam to power a conventional turbine/generator.

In recent years, the use of a molten-nitrate salt has emerged as the preferred heat transfer fluid. The advantage of using salt is that it provides a simple and cost-effective energy storage system. This energy storage system gives central receivers unique advantages over other solar technologies: 1) electricity can be dispatched when desired (even at night) to meet the needs of the utility grid, and 2) plants can be cost-effectively designed with annual capacity factors ranging from 25 to over 60 percent, without using fossil fuels. In addition to these unique advantages, studies performed by industry predict that these plants will produce the lowest cost electricity of any utility-scale solar power plant that can be built with today's technology.

With the conclusion of a test to prove commercial-scale pumps and valves last October, all major subsystems in the molten salt power plant have been demonstrated. Sandia now has an extensive data base to allow a realistic prediction of the cost, performance, and reliability of molten salt power plants. The next logical step is to build a pilot plant. The purpose of the pilot plant is to demonstrate a total power plant in order to reduce the perceived risk by future investors in the technology. To date, the conversion of Solar One to a molten salt plant appears to be the most likely candidate, though others are being considered.

Sandia National Laboratories is helping the utility industry form a consortium to build the pilot plant. We are doing this by meeting with utilities, IPPs, energy commissions, public utility commissions, and environmental regulatory groups located in the sunbelt states. To date, we have identified several groups that appear interested in contributing to such a project.

DEVELOPMENT OF AN INDUSTRY CONSORTIUM TO BUILD A CENTRAL RECEIVER POWER PLANT

Greg Kolb, Jim Chavez, Dan Alpert
Sandia National Laboratories
Albuquerque, New Mexico

March 28, 1991

Sandia is helping industry form a consortium to build a molten-salt pilot plant

WHY is Sandia doing this?

- All major subsystems have been demonstrated
  - Commercial-scale pumps and valves were the final major components to be demonstrated (October 1990)

- Current focus on the environment will result in public support for this technology

- A pilot plant may be necessary to increase investor confidence in this technology
  - A pilot plant will cost tens of millions of dollars
  - A consortium of industry and government partners is needed to finance this project

Sandia is helping industry form a consortium to build a molten-salt pilot plant

HOW is Sandia doing this?

- Technical presentations that highlight merits of this technology given to organizations within Sunbelt
  - Utilities
  - IPPs
  - State energy commissions
  - Public utility commissions
  - Environmental regulation groups

- Sandia is identifying interested parties for the consortium

HIGHLIGHTS OF SANDIA'S TECHNICAL PRESENTATION

(a.k.a. ''The Road Show'')

TODAY'S CENTRAL RECEIVER POWER PLANT TECHNOLOGY

January 1991

Greg Kolb, Dan Alpert, and Jim Chavez

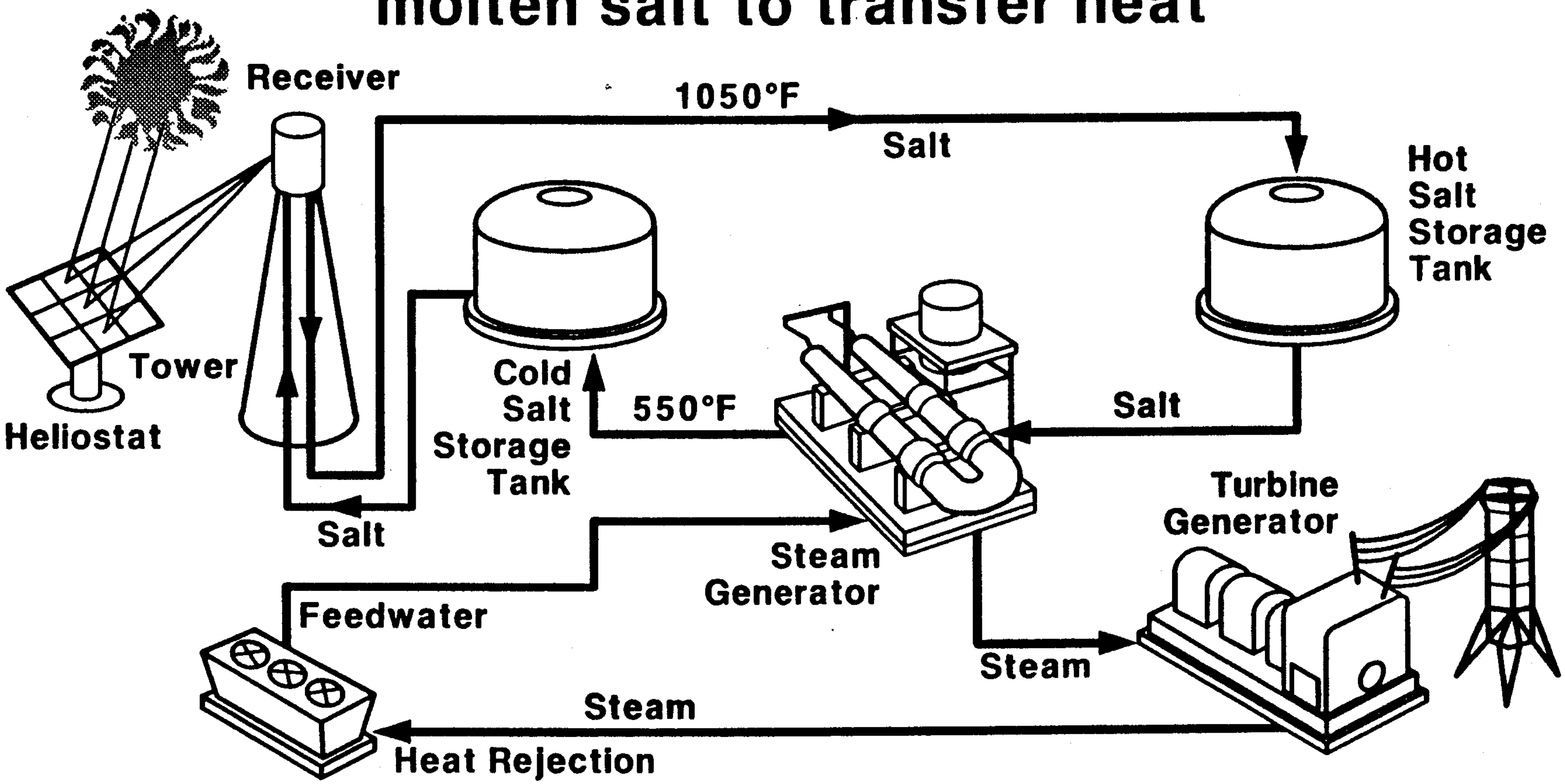
Sandia National Laboratories
Albuquerque, NM 87185
(505) 846-1976

WHY A SOLAR CENTRAL RECEIVER POWER PLANT?

- Will produce lowest cost electricity of any utility-scale solar power plant
- Practical energy storage for dispatchability and high capacity factor (more than 60%)
- Environmentally benign

90K6000.17

Today's central receiver technology uses molten salt to transfer heat



DJR 11/90
90J6000.54

Schematic of a molten-salt central receiver system

Sandia National Laboratories

WHY USE MOLTEN NITRATE SALT?

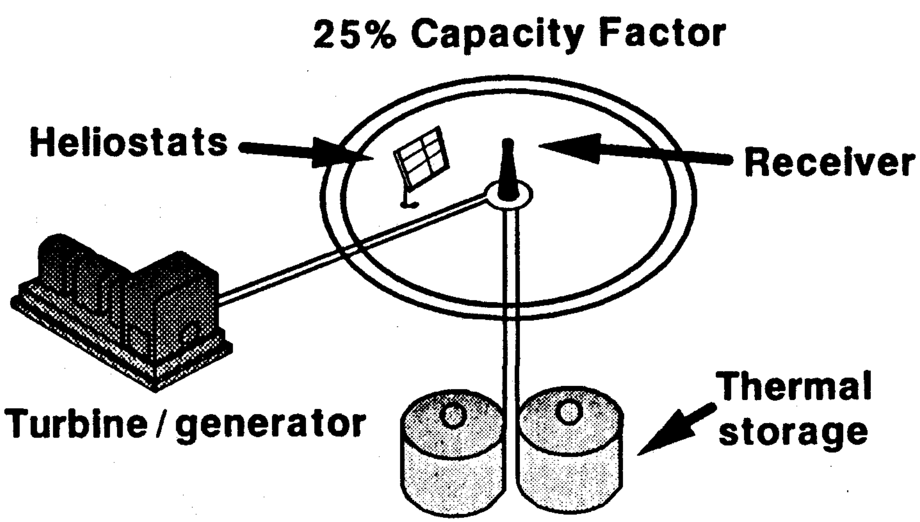
- Single-phase fluid
- Simple and compact energy storage
  - Decouples receiver and turbine
  - Improves plant efficiency
- Operating temperature (1050°F) compatible with high-efficiency steam turbines
- Safe

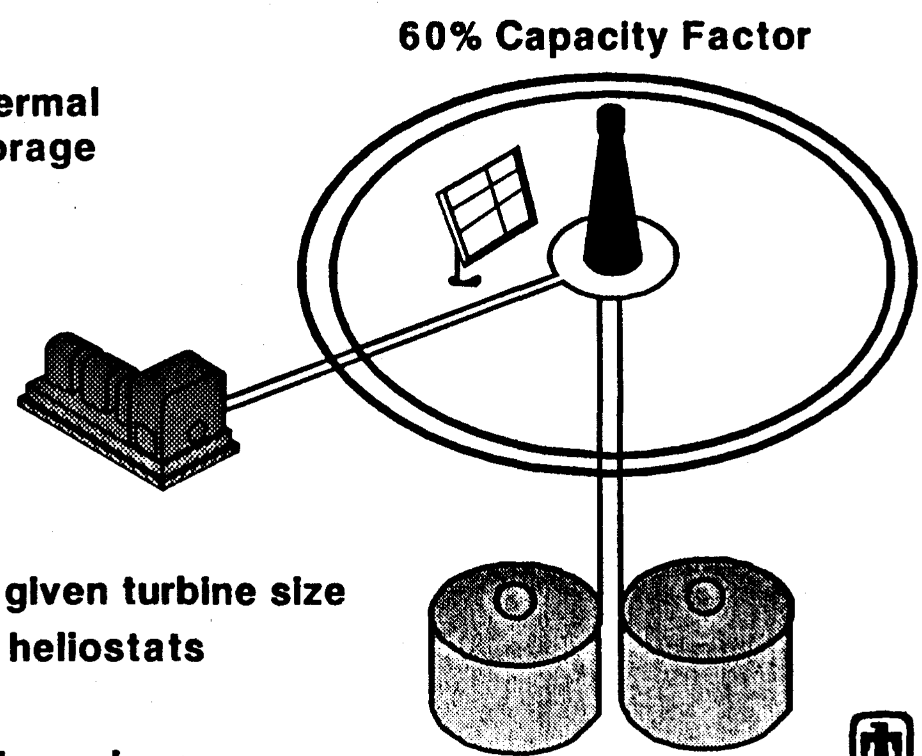
90K6000.40

AMONG ALL SOLAR TECHNOLOGIES CENTRAL RECEIVERS ARE UNIQUE

Economical and efficient (99%) thermal storage provides:

- High capacity factors (up to 60%)
- Practical dispatchability and load shifting



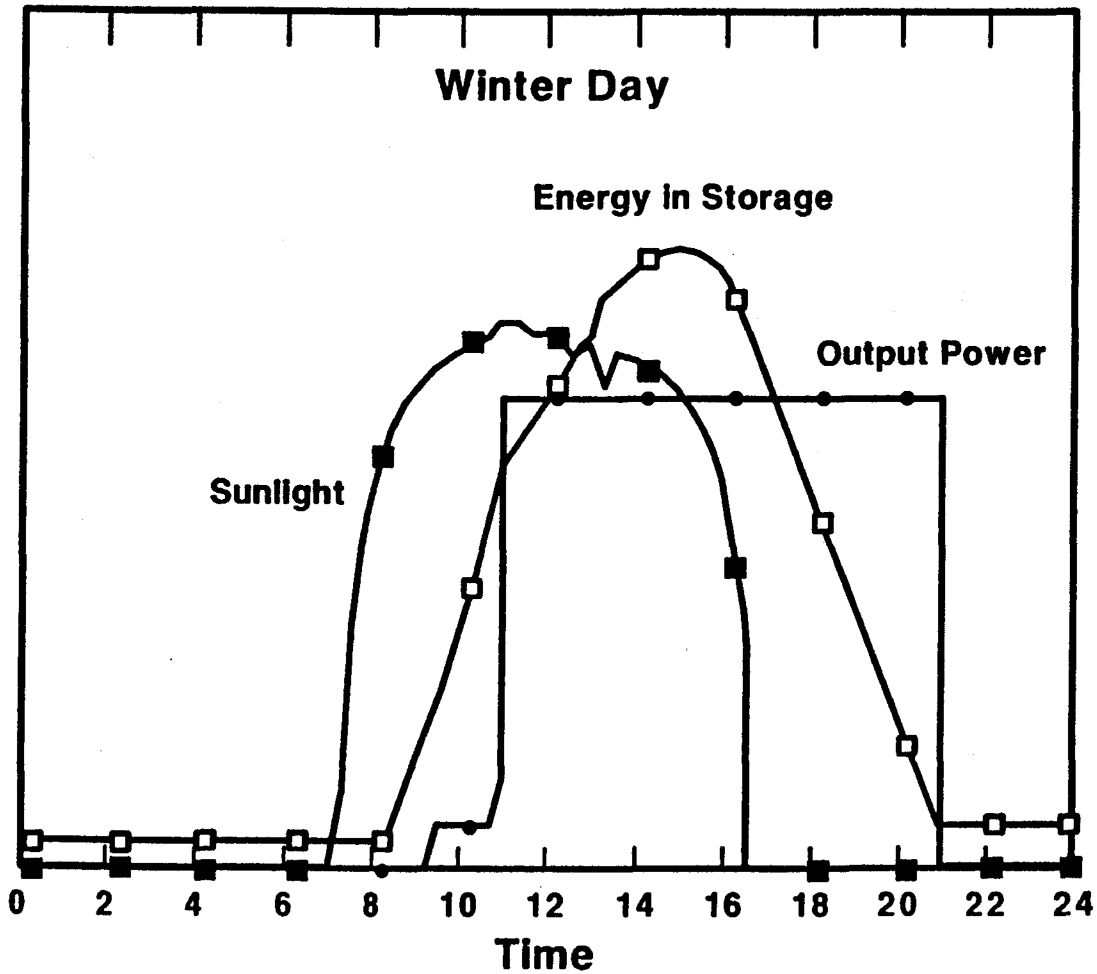


To increase capacity factor for a given turbine size

- increase number of heliostats
- enlarge storage
- raise tower
- increase receiver dimensions

90L6000.01

LOAD SHIFTING CAPABILITY OF CENTRAL RECEIVER PLANTS



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SANDIA HAS RECENTLY COMPLETED IMPORTANT EXPERIMENTS ON COMPONENTS FOR CENTRAL RECEIVER PLANTS

- Technical feasibility has been proven
- Cost, performance and reliability can be confidently predicted
- Central receiver technology is ready for commercialization

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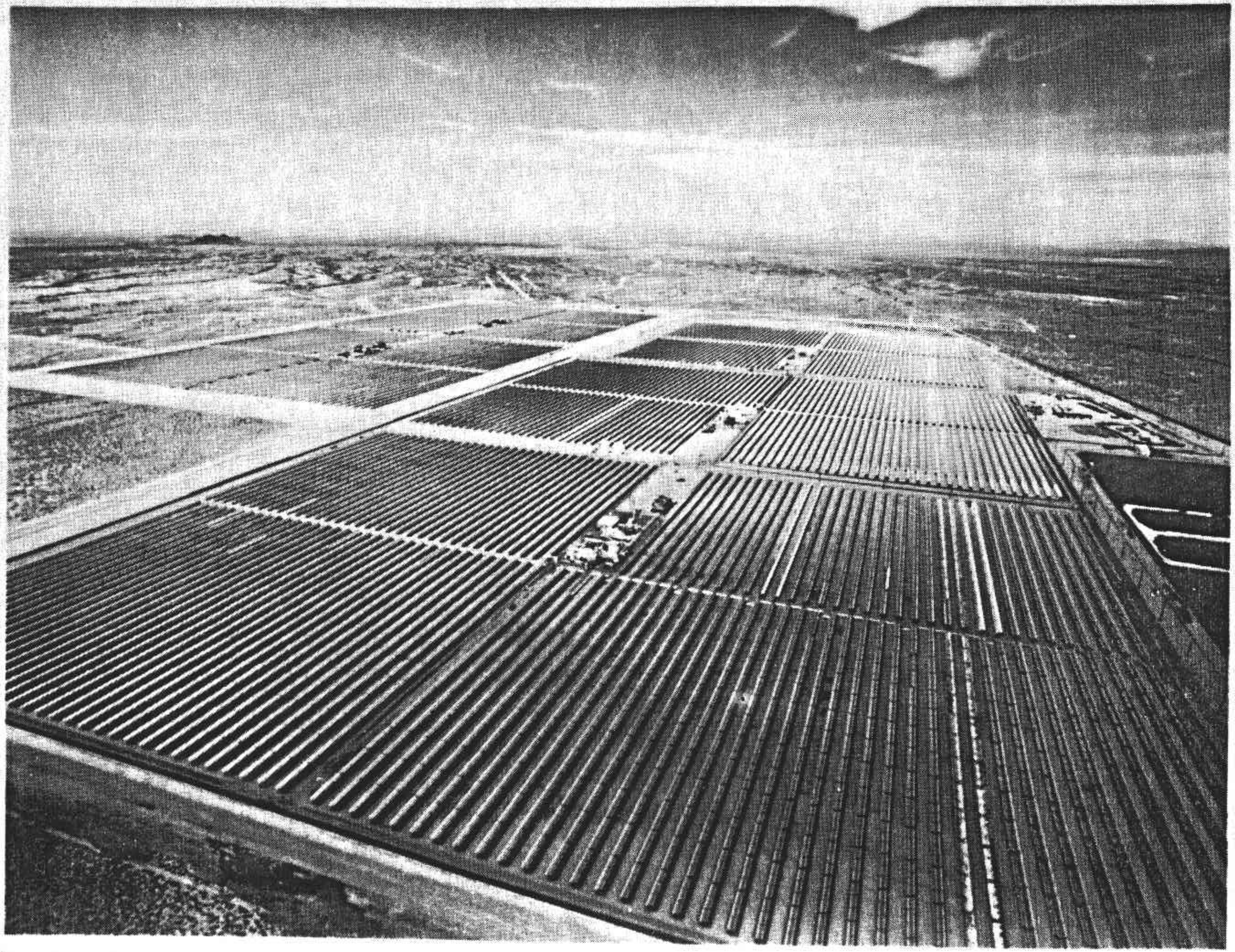
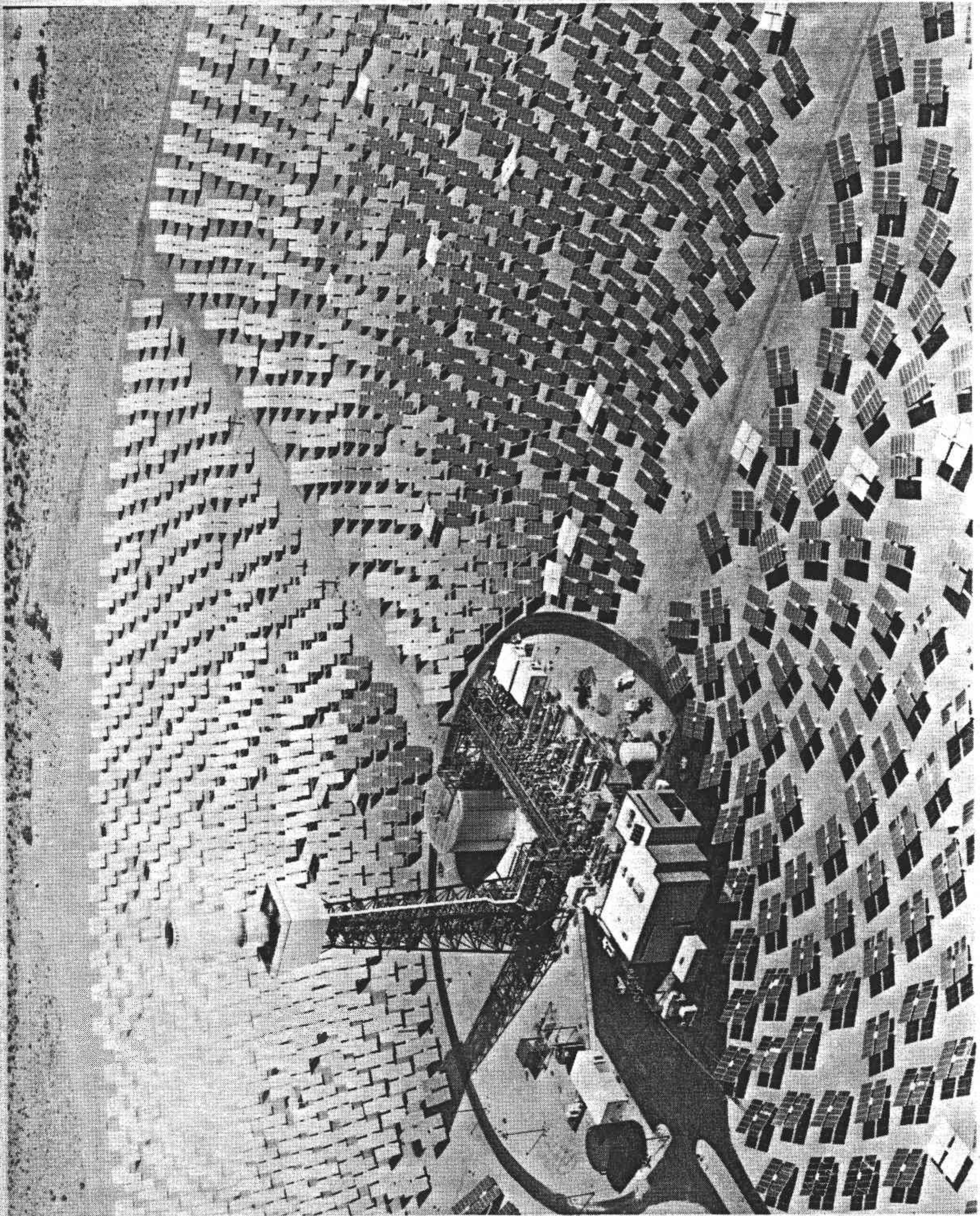
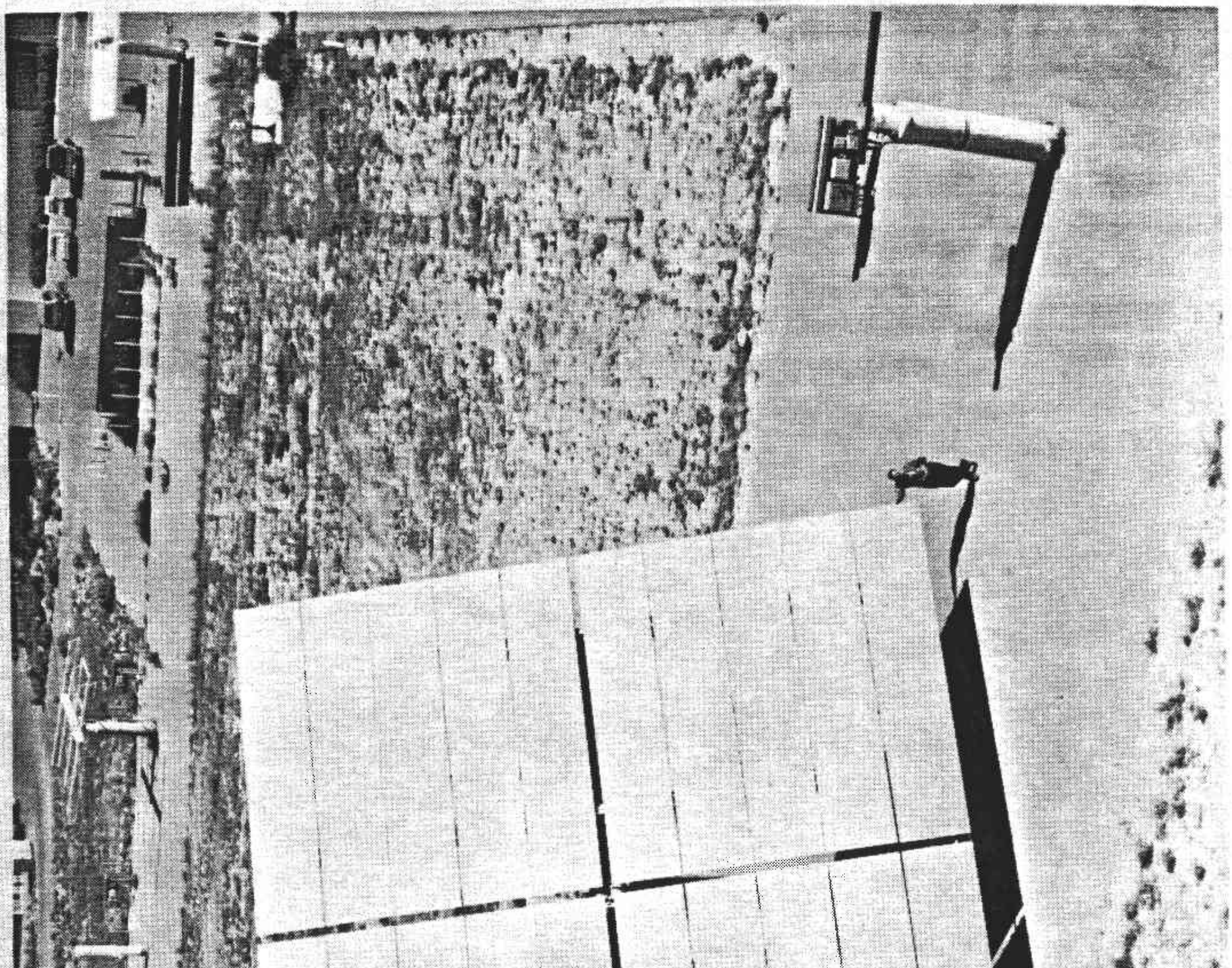
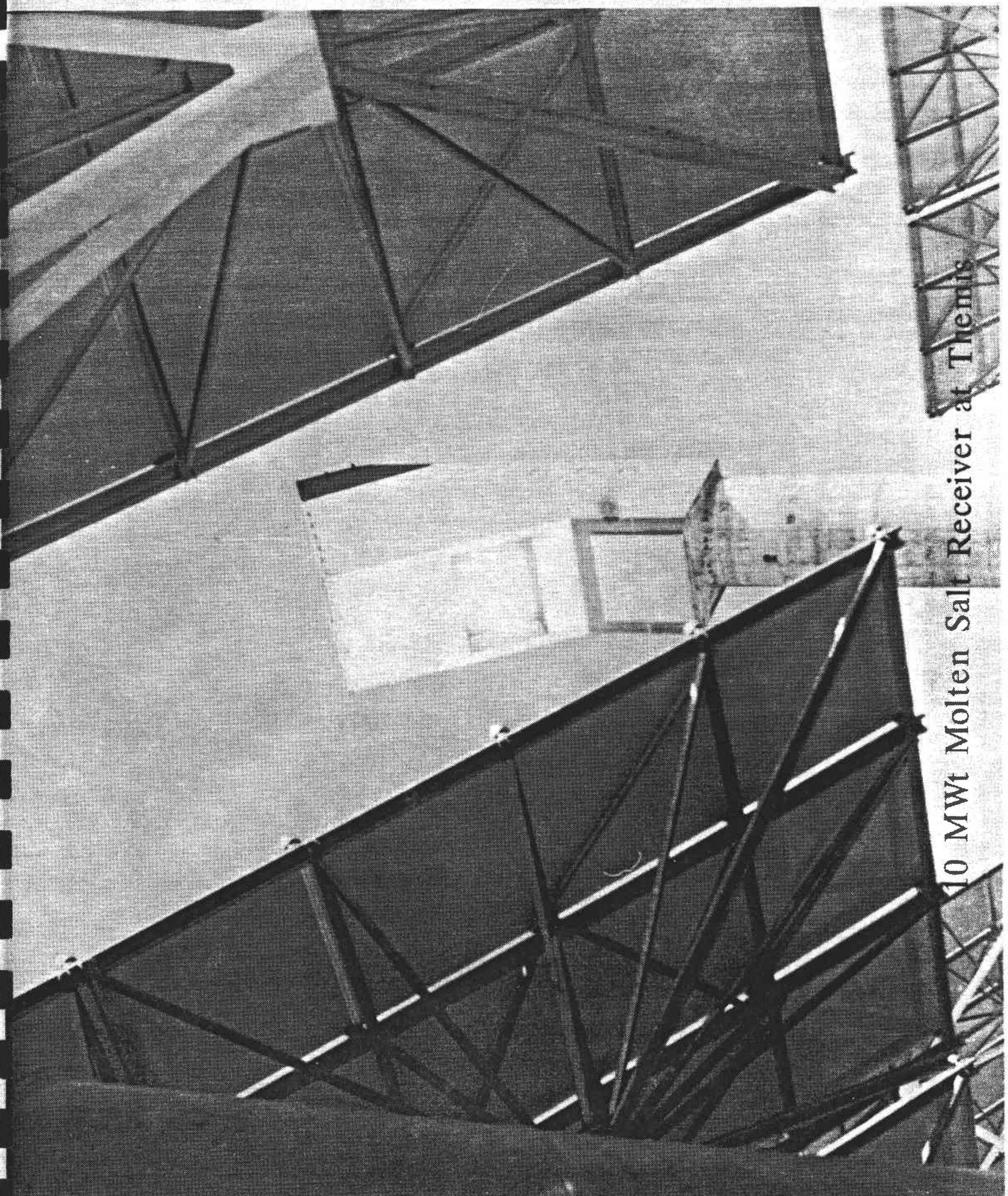


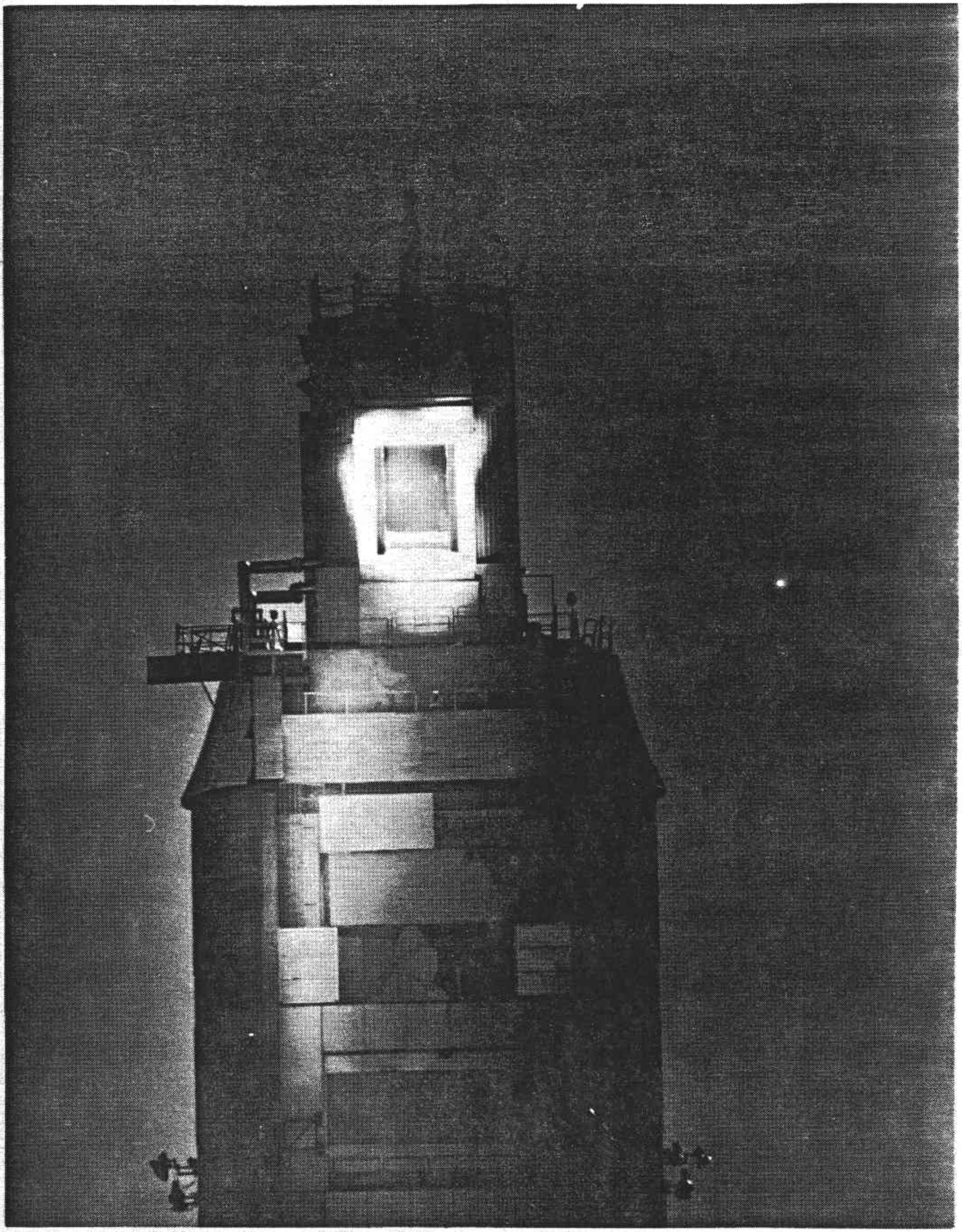
AERIAL VIEW OF SEGS PLANTS, KRAMER JUNCTION, CALIFORNIA



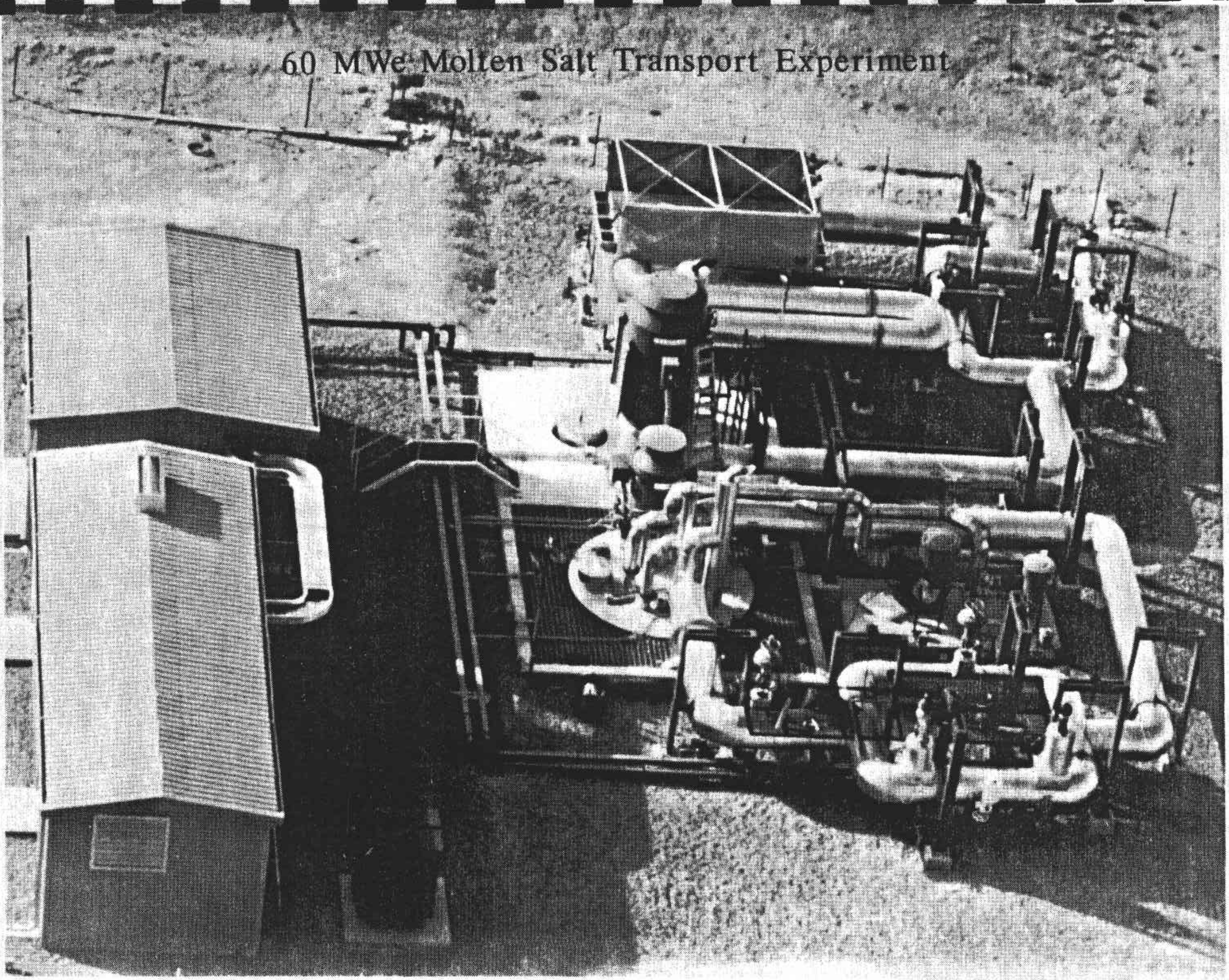




10 MWt Molten Salt Receiver at Themis



5 MWt Molten Salt Receiver


60 MWe Molten Salt Transport Experiment

RESULTS FROM RELIABILITY ANALYSIS

Forced Outage Rate	5.4%
Scheduled Outages (2 weeks)	3.8%
Availability	91%

90K6000.32

ADVANCED THERMAL SYSTEMS, INC.

Rockwell International
Rocketdyne Division

CBI INDUSTRIES

PG&E
Pacific Gas and Electric Company

SERI

SAIC
Science Applications International Corporation

McDONNELL DOUGLAS CORPORATION

Stearns-Roger

PRECISION CONTROLS AND INSTRUMENTATION

SPECO

SOLAR POWER ENGINEERING CO.

DEPARTMENT OF WATER AND POWER

Sandia National Laboratories

SOLAR KINETICS INC.

PDM PITT-DES MOINES, INC.

Southern California Edison

MARTIN MARIETTA

EPRI
Electric Power Research Institute

UH UNIVERSITY OF HOUSTON

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION

BLACK & VEATCH ENGINEERS-ARCHITECTS

B&W BABCOCK & WILCOX

Olin OLIN CORPORATION

APS. ARIZONA PUBLIC SERVICE COMPANY

Bechtel National, Inc.
Engineers—Constructors

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

U.S. Department of Energy

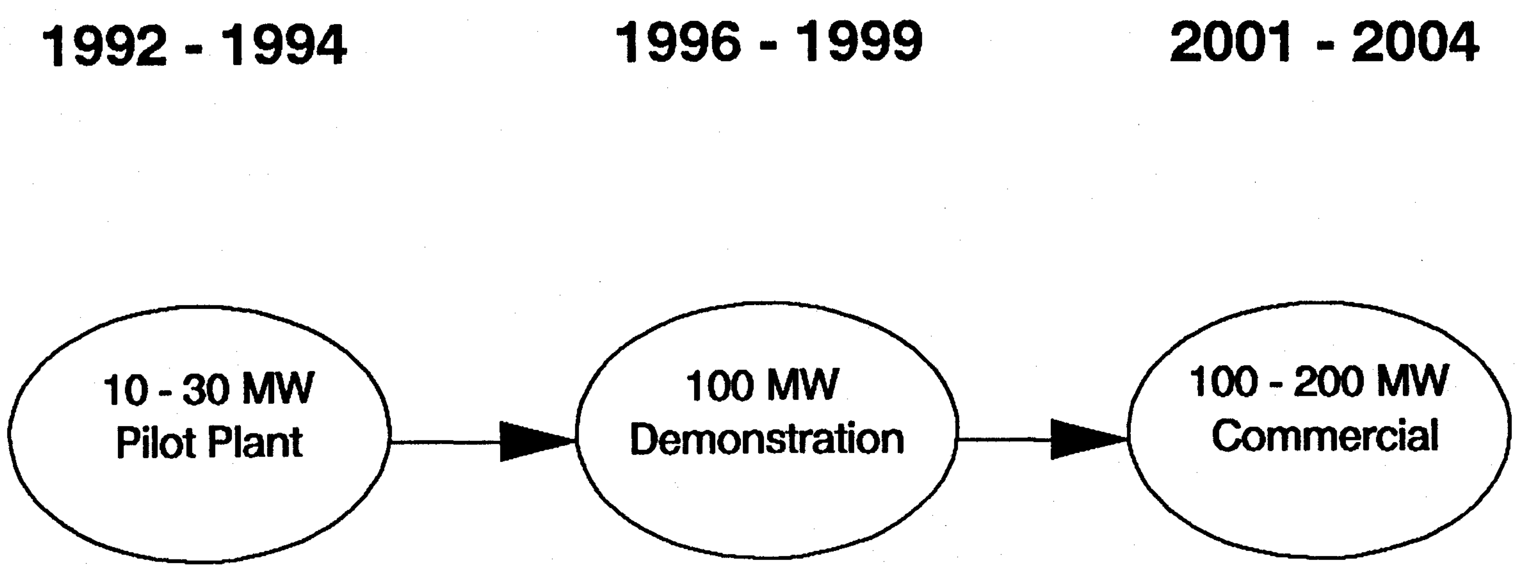
Comparison of Levelized–Energy Costs

– Central receivers will provide the lowest cost electricity of any utility–scale solar power plant

– Plants using current technology would cost only 1 to 2 cents per kilowatt–hr more than a coal plant of similar size
  – Adding external costs to burning fossil fuels will favor central receivers over coal

– Plants using future technology will beat coal without consideration of external costs

Solar Central Receiver Commercialization Strategy



IN SUMMARY . . .

- Central receivers meet the needs of today's utility grids
- Technology is proven
- Cost, performance, and reliability can be confidently predicted
- Competitive electricity costs
- The time is right to build the plant that starts commercialization development

90K6000.38

ABSTRACT

Externalities in Electric Generation Planning and Development - A California Status Report

Alec Jenkins
California Energy Commission

Externalities have had an important role in California energy policy since the formation of the California Energy Commission in 1974. For example, the Warren-Alquist Act establishing the Commission requires that the planning and approval of new energy resources balance requirements of growth with protection of public health, environmental quality, and conservation of resources.

Similarly, a recent amendment to the Warren-Alquist Act requires the Energy Commission to include values for costs and benefits to the environment in minimizing the costs of energy services, and to encourage diversity through renewable energy technologies.

These requirements motivate increasingly detailed valuations of externalities, and expression of the valuations in commensurate monetary units.

Externalities are defined as discrepancies between private and social costs, or private and social benefits. The renewable energy community, a large segment of the public, and many energy policy makers believe that a careful accounting and valuation of the externalities of renewable and conventional energy technologies would weigh significantly in favor of some renewable technologies, and thus accelerate their use.

The valuation of externalities can take place in two ways: through contrived market mechanisms which internalize the externalities to market transactions (the market for air emission offsets is one example), and by incorporating externalities in institutional processes. As externalities become institutionalized they become less visible, and their role in decision making becomes less understandable outside of the institution.

The Energy Commission's earliest attempts at valuation consisted of descriptions and characterizations of externalities. These efforts were followed by the ranking and weighing of externalities in order to support a more rational decision process. More recently, the cost of abatement (i.e. "control") approach has been used to approximate social costs. In ER-90, the Commission's biennial Electricity Report, and in the Luz SEGS IX siting decision, the costs of controlling air emissions to their regulated levels, of purchasing offsets for new emission sources, and of controlling residual emissions (those emissions which are within the standards), are used as a proxy for social cost in developing least cost electricity supply plans and in siting new power plants.

The Energy Commission is sponsoring research aimed at the

development of a full costing methodology and data base for a number of externalities, based on the concept of avoided marginal damage, which include the effects of air emissions on human health, animals, vegetation and materials. Air emission source identification and air quality modeling are available due to state and federal air quality regulation. Current research is targeting development of dose-response functions to relate changes in air quality to physical effects on an exposed population, and to express these effects in monetary terms. Thus, the social cost of a change in air quality resulting from a certain electricity development strategy in an air basin can be combined with the cost of the electricity provided by that strategy, and compared to the cost of an alternative electricity strategy. Future social cost research will include valuations for other externalities, such as land and fresh water use.

The energy policy process offers many points for application of the results of successful costing of externalities. There are a number of regulatory procedures within the jurisdictions of the Energy Commission and the California Public Utilities Commission where social costs can be directly applied to energy resource decisions. By statutory requirement, the two Commissions must apply the same cost factors for externalities to their respective decisions. The Public Utilities Commission is the approving authority for research and development sponsored by investor-owned utilities, for the terms of competitive bidding between a utility and QFs for the right to build new generation capacity, and for the standard offer terms for QF and demonstration projects.

The Energy Commission influences utility and QF consideration of new generation through the Electricity Report, and through its Energy Development Report which identifies "opportunity technologies" of special benefit to balanced electricity development. Further, the Energy Commission approves construction and operation of thermal power plants 50 megawatts and larger in its siting process. The Commission evaluates external costs and benefits of proposed plants, as it did for the Luz SEGS IX application, and reviews plants proposed as demonstrations of new technology for the long term value of the technology to California.

There are systems outside of energy with externalities which affect energy resource choices inequitably, and taxation is one of these systems. For example, a Luz SEGS plant, over 30 years and including the state 10 percent solar tax credit, pays almost four times the taxes (sales and property) which an equivalent combined cycle plant pays, unless the solar portion of the Luz plant is exempt from property taxes. There is no sales tax on natural gas.

A sensitivity analysis of the levelized cost of electricity for a Luz SEGS plant shows that crediting the SEGS plant with the value of the emissions reduction due to the solar portion of the plant using ER-90 cost factors has the same impact on levelized cost as crediting the plant with a property tax exemption on the solar portion of the plant (about 6.7 percent for each externality).

Externalities in Electric Generation Planning and Development ... A California Status Report

Alec Jenkins
California Energy Commission
March 28, 1991

Topics

- Brief History of Use of Externalities at CEC
- Current Institutional Processes Using Externalities
- Research on Valuing Externalities
- Application of Externality Valuations

Messages

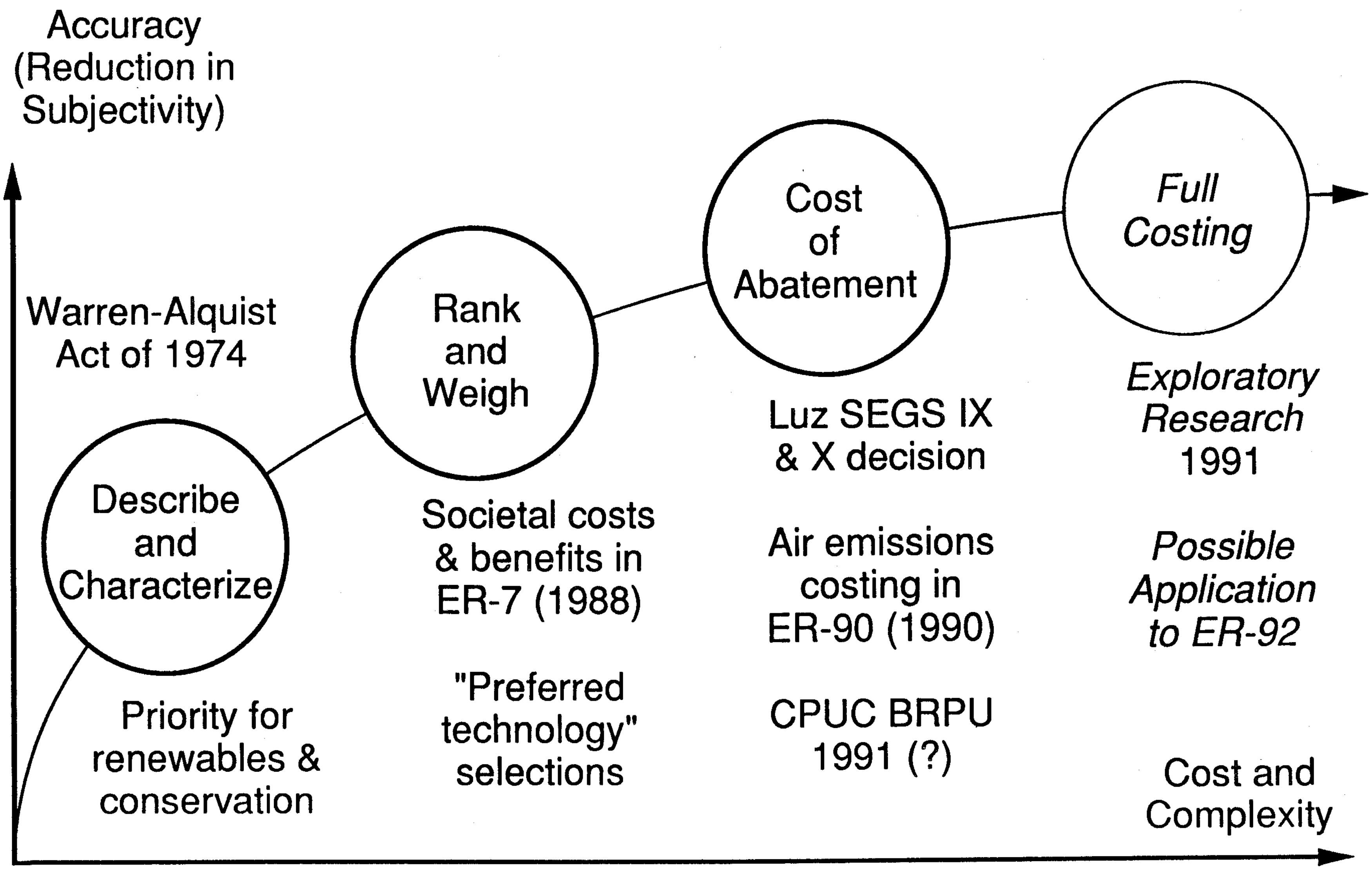
1. Externalities are becoming more internalized in institutional process, compared to becoming internalized in market process.

2. Research is under way to estimate the full costs of certain externalities, compared to the cost of abatement methodology currently used at the CEC.

3. There are systems with externalities outside of energy systems which affect energy choices inequitably. The taxing system is one of these.

4. The valuation of externalities has become extremely important to the approval of solar thermal electric plants - and if, for the purpose of comparison, this value could be directly credited to Luz, it would be worth as much as the property tax exemption.

History of Applying Externalities



Assembly Concurrent Resolution 160 (Sher, 1988)

CPUC standard offer update proceedings, and

CEC resource planning process,

Shall take into account nonprice factors, such as:

- Diversity
- Environmental factors
- Employment
- Busines development
- Vulnerability

Assembly Bill 3995 (Sher, 1990)

A principal goal of electric and gas utilities is to minimize the <u>cost to society</u> of reliable energy.

CEC and CPUC shall:

- Include values for costs and benefits to the environment.
- CEC/CPUC shall document reasons for different values.

Externalities Defined

- Non-market impacts from market transactions
- Discrepancies between private and social costs/benefits
- Frequently called "non-price" transactions

Since externalities do not come to us through market processes with valuations attached, we have to:

- Identify externalities, estimate valuations, and
- Contrive market mechanisms to internalize the externalities,
  or
- Find equitable ways to internalize the externalities in institutional processes.

Application of Externality Values at the CPUC

- Balanced planning for environment and development

  Setting competition rules for capacity additions

- Accepting projects as "demonstrations"

  Approving Standard Offers for demonstrations

- Evaluating utility RD&D plans during ratemaking

Process

Application of Externality Values at the CEC

- Balanced planning for environment and development

  Identifying supply mix with least societal cost

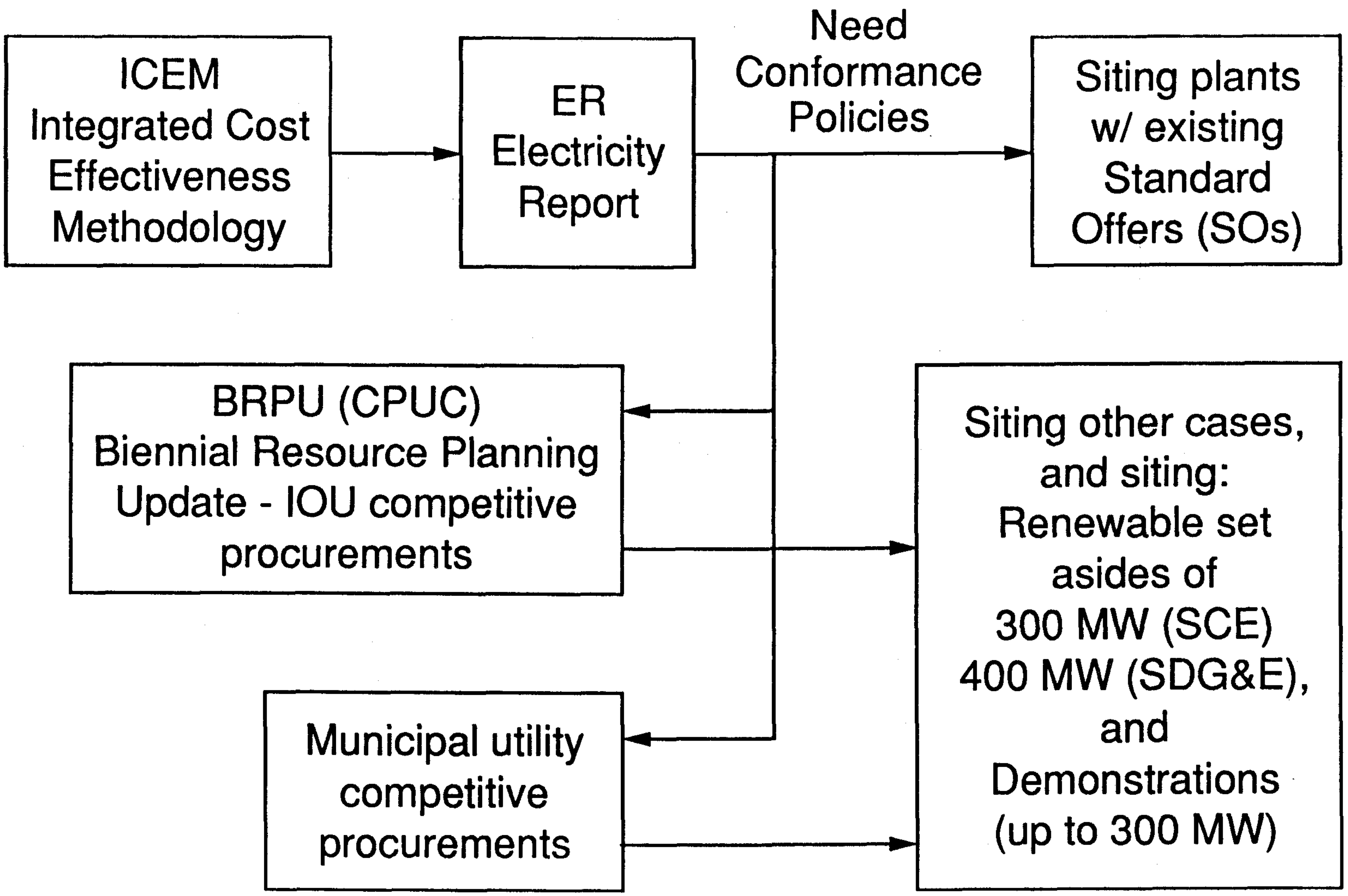
  Identifying "opportunity technologies"

  Set-asides for renewable technologies

- Designating "demonstration" projects
- Selecting winning RD&D proposals
- Establishing impact mitigation levels in AFCs
- Evaluating the cost-effectiveness of a proposed plant

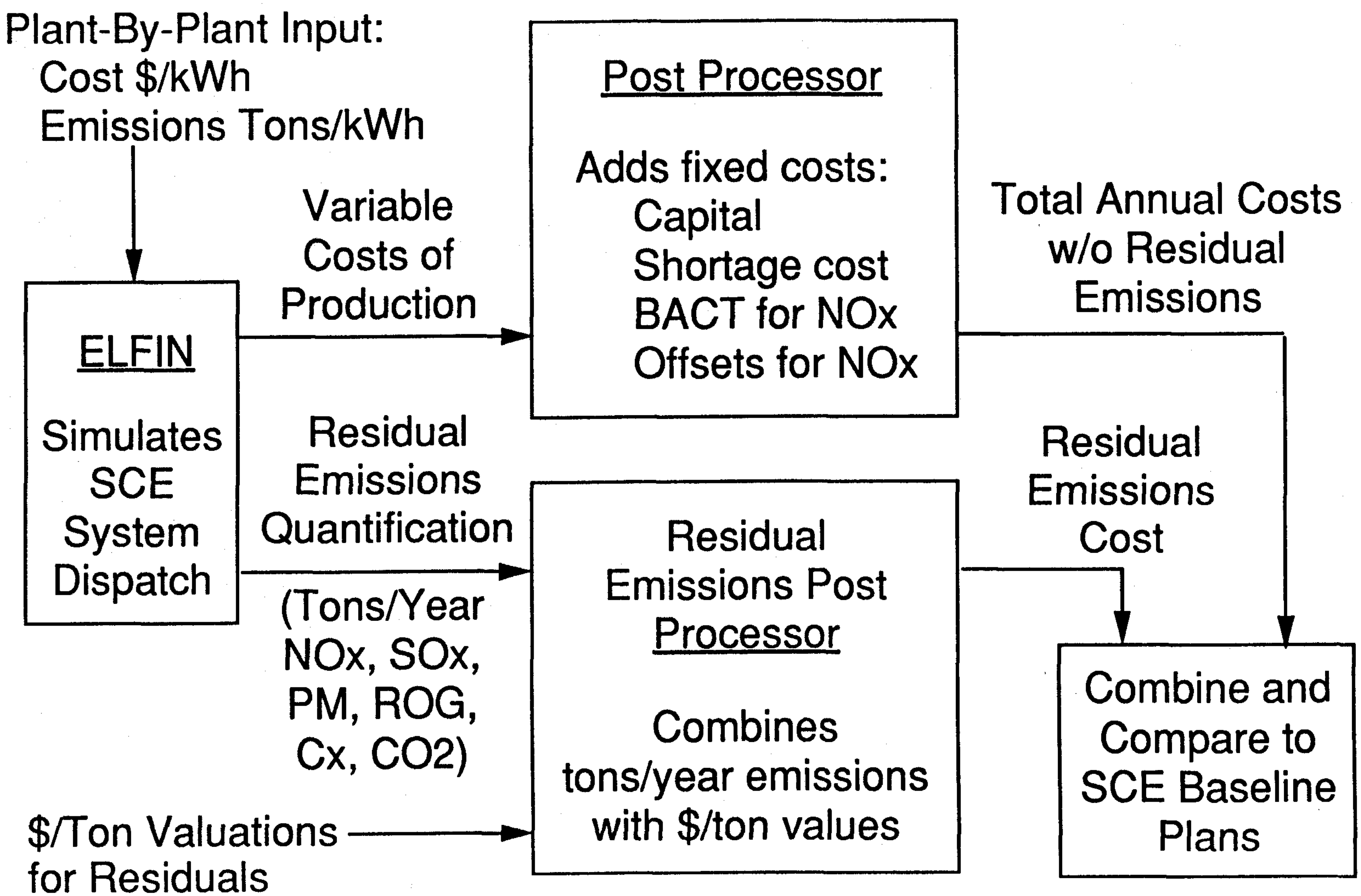
Process

Institutional Processes - Resource Decisions



Process

Integrated-Cost Effectiveness Methodology (ICEM)



Factors for Social Cost (Cost of Control in SCAQMD)

Regulated emissions:

- 90% control of NOx for gas turbine & combined cycle plants:

  New plants: $45/kW, one time

  Retrofit of plants: $72/kW, one time

- Offset for new sources of NOx is $45/kW, one time

Major residual emissions:

- NOx: $18,959/ton, annually
- Carbon: $30/ton, annually

ER - 90's Incorporation of Externalities

Based on Southern California Edison Territory

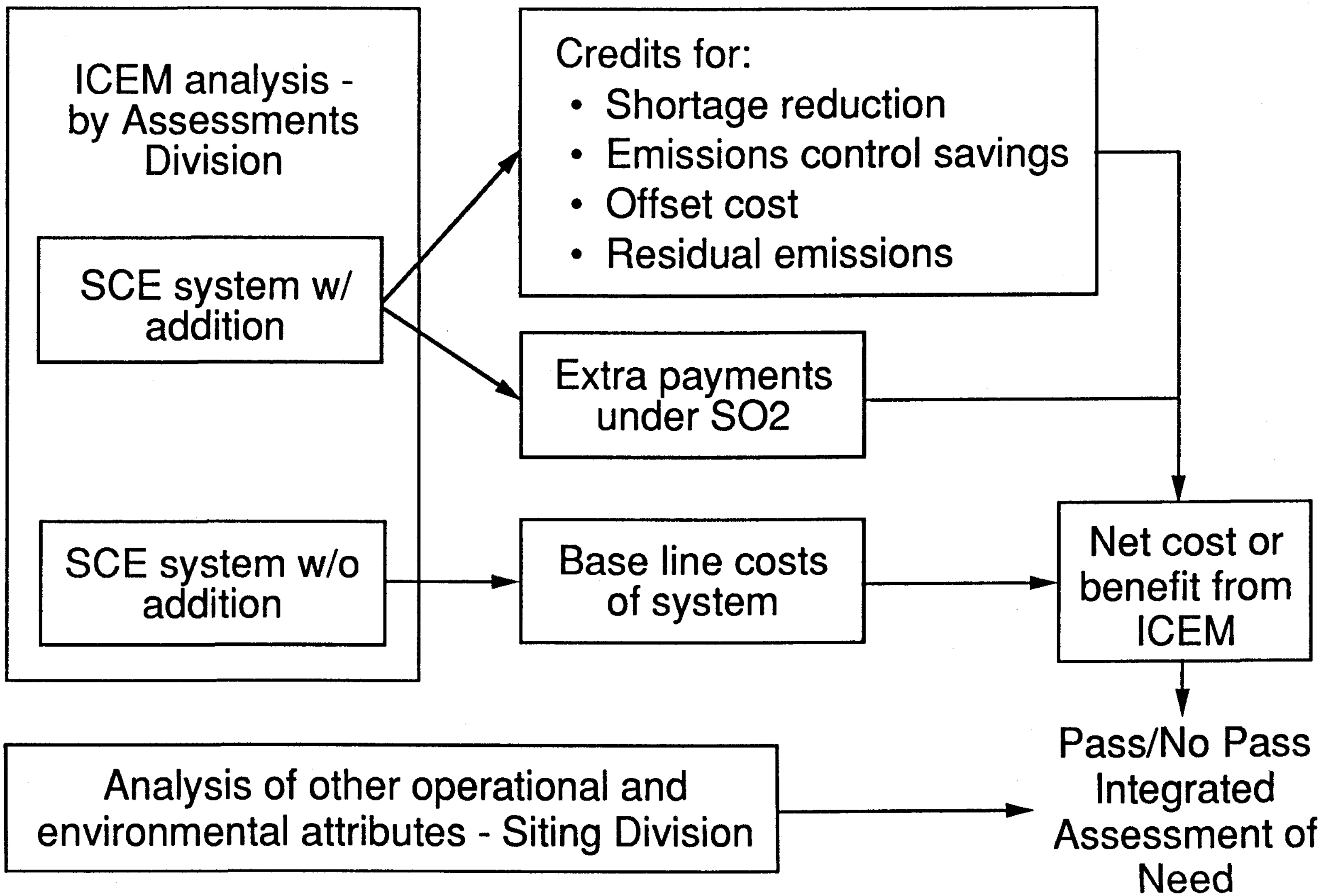
The "societal costs" are added to electricity production cost in ICEM

Results:

- Narrows cost-effectiveness gap between renewable and new gas fired generation
- But, accelerates new gas fired generation by one to two years
- Cost of residual emissions would have to be 4-10 times higher to reverse cost- effectiveness position between renewables and new natural gas fired plants

Process

Social Cost/Benefit Analysis for Existing SO Contract



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SITING, BASED ON VALUING EMISSION REDUCTION

	CEC	Luz
Value of NO_X reduction based on:		
SCE average cost of control	\$17	
SCE marginal cost of control	\$20 to 49	\$63
Social Benefits (final approach):		
NO_X	\$37 to 73	\$49 to 103
Other criteria pollutants	\$9	\$9 to 20
CO_2	\$24 to 52	\$21 to 39
Total, with rounding	\$69 to 134	\$79 to 162
Compared to direct costs to ratepayers of the Luz facilities:	\$131 to 134	\$93 to 103

Exploratory Work in Full Costing of Externalities

Air emissions on:

- Human health
- Materials
- Vegetation - agricultural and non-agricultural
- Materials
- Visual aesthetics

Water quality impacts on human use:

- Residential, commercial, industrial, and agricultural

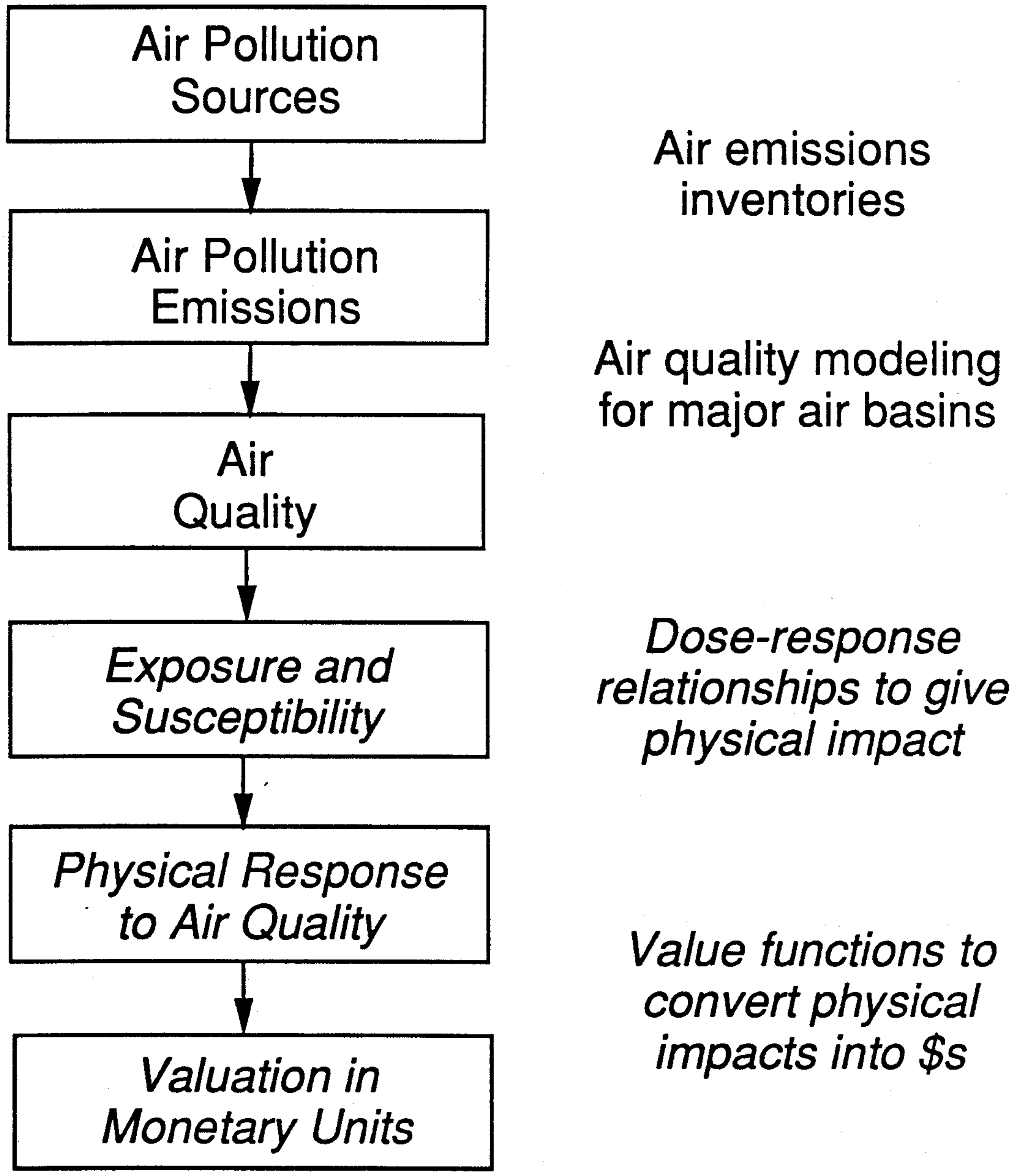
Biological impacts through use of:

- Air
- Water
- Land

Research

Full Costing for Air Emissions

Explore a methodology for objectively converting air emissions into costs of impacts on human health.



Externalities of a Second Kind

Impact of Externalities of Other Systems on Solar Energy

- Fossil fuel emissions on the solar resource (5% to 15%)
- Sales and property tax structure

Application

State and Local Tax Revenues from Comparable Solar and Fossil* Fuel Plants Without SB 103

	Luz Solar Plant	Natural Gas Combined Cycle Plant
State solar tax credit (10%)	- $20,000,000	--
Sales tax (6.5%)	$8,900,000	$1,800,000
Net first year tax revenue	- $11,100,000	$1,800,000
Property tax (1%/year, 30 years life)	$60,000,000	$11,600,000
Net 30 year tax revenue	$48,900,000	$13,400,000

* Luz 80 MW, 35% CP ($200 M capital cost, $137 M sales taxable)
Combined cycle, 80 MW, 35% CP ($40 M capital cost, $27 M sales taxable)

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Application

Relative Value of Selected Options

Sensitivity analysis for current Luz SEGS technology. Base case: no 10% solar tax credit, and full sales and property taxes.	Percent Improvement in Levelized Cost of Electricity Relative to Base Case
1. Credit the reduction in air emissions from solar portion of plant, only. (Costs of controls, offsets and residual emissions using ER - 90 cost factors *)	**6.7 %**
2. Property tax on fossil portion, only. (SB 103, as amended)	**6.7 %**
3. Sales tax on fossil portion of plant, only.	**2.8 %**
4. Apply existing 10 percent state solar tax credit.	**7.7 %**
Combining (1), (2) and (3). (Credit for emission reductions and more equitable property and sales tax treatment)	**17.3 %**

*** Note:** This is not equivalent to the ICEM process used at the California Energy Commission.

THE HAWAII EXPERIENCE: PROBLEMS WITH GEOTHERMAL ENERGY DEVELOPMENT AND THE GROWING OPPORTUNITIES FOR SOLAR THERMAL ELECTRIC TECHNOLOGY

by Andrew R. Trenka
Director, Energy and Resources Division
Pacific International Center for High Technology Development

ABSTRACT

Exploration for geothermal energy for producing electricity has been conducted for 30 years in Hawaii. In 1976 the first successful geothermal well was completed, and a 3 MW demonstration plant was completed in 1981 on the Big Island. This plant operated for eight years and demonstrated that electrical power could be generated on an active rift zone on the Island of Hawaii. This accomplishment appears to indicate that the development of geothermal energy on a large scale would be readily feasible, and a number of geothermal developers began preparations to construct commercial power plants. However, a series of environmental, technical, economic, cultural, and social barriers to development have been encountered. Operation of the demonstration well has been terminated, and although several exploratory geothermal wells have been drilled on the Kilauea East Rift Zone, developers have not succeeded in completing a commercial geothermal power plant to date. Public resistance to large-scale geothermal development and a plan to transmit power from geothermal plants on the Big Island to other islands in the state, combined with the economic and technical problems that have plagued the effort, have resulted in an opinion by some energy planners that other renewable energy technologies, in particular concentrated solar thermal technology, should be investigated as a means of electricity production to reduce Hawaii's high dependence on imported fuels. Although the market for electricity from alternative sources on the Big Island is limited, opportunities for solar thermal energy development appear most favorable on other islands such as Maui, Oahu, Molokai, Lanai, and possibly Kauai.

THE HAWAII EXPERIENCE

ALOHA — Greetings from Hawaii

Islands of Sea — Sun — Madam Pele — and Tourists

Gate Way to Pacific

and

Unique Opportunity for *Solar Technologies/Industry*

CHARACTERIZATION OF DEMAND

Population — 1.2 million - consumed 313 trillion BTU's
285 million BTU's/person or
45 barrels of oil/person
All of it brought in by tanker!
91% of all energy needs is oil

Utilization — 45 million barrels of oil used

Transportation	— 58% of which 1/2 jet
Electric Utilities	— 22%
Commercial	— 12% (no heavy industry)
Residential	— 8% (no heating/limited air conditioning)

A Growing Need — Water

Characterization of Demand (Cont'd)

Supply —	**Oil**	**~**	**91%**	**(electricity)**
	Biomass	**~**	**8%**	**(cogen)**
	Renew	**~**	**2%**	**(solar hot H_2O/hydro/ wind/geothermal)**

This despite a State objective — energy independence by 2020

THE HAWAII EXPERIENCE: PROBLEMS WITH GEOTHERMAL ENERGY DEVELOPMENT AND THE GROWING OPPORTUNITIES FOR SOLAR THERMAL ELECTRIC TECHNOLOGY:

- Hawaii's renewable resources and petroleum dependence
- Problems and issues (history of geothermal efforts)
- Opportunities for Solar Thermal Electric Technology
- Conclusions and recommendations

Regarding State's Uniqueness

- 91% Oil dependence
- High transportation fuel needs
- Distribution — are islands!
- Great abundance and variety of renewable resources

Constraints

- No nuclear
- Indigenous fuels limited to biomass and wastes
- Very high cost of land
- Geographic isolation (benefit and hindrance)

STATE IS STRUGGLING FOR WORKABLE PLAN/STRATEGY

- Electricity/transportation focus
- IRP - PUC's/public hearings
- Renewables focus
- Demand and supply side recognition

<u>Perspective</u>

- Hawaii sees itself as a role model for Pacific
  - Demographically
  - Geographically
  - "Gateway to Pacific"

WHAT IS IT DOING NOW - STRUGGLING TO COMPLETE AN IMPLIMENTABLE PLAN AND SUPPORTING INTERIM MEASURES

- Restudy of its energy policy
  - — IRP
  - — State reorganization - Energy Division in Cabinet Post (under consideration)
- Seriously looking at methanol/ethanol fuels
- Increased tax credits for Solar Hot H_2O Systems to 35% ($1750 - Max)
- Currently investing approximately $10M/Year in renewable energy technology development

HAWAII'S ABUNDANT RENEWABLE ENERGY RESOURCES

- Excellent wind regimes
- Good insolation
- Biomass (municipal solid wastes; bagasse)
- Ocean thermal
- Geothermal (heavy focus)
- Some hydropower

OPPORTUNITIES FOR SOLAR THERMAL ELECTRIC TECHNOLOGY

- Environmentally attractive
- Supportive Government policies
- Favorable insolation
- Rapid growth of Hawaii
- Application in other Pacific Islands

WHAT PROJECTS ARE UNDER WAY

- Wind
  - Kahuku Pt. - wind farm (1 unit @ 3.2MW; 15 units @ 600KW each)
  - Kahua Ranch WF (197 units @ 17.5KW each)
  - South Point - Mitsubishi (37 units @ 250KW each)
  - Several - wind diesel projects
  - Need: A wind machine designed for unique Island application

- PV
  - PV USA ~ 20KW system on Maui
  - Ka'ahele La (Tour the Sun) grand prize DOE's best education program
  - Small residential units

- Solar thermal
  - Milolii - 35 unit low income housing 2400 people - 7 year pay back

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What Projects Are Under Way (Cont'd)

- LUZ assessment study/DBEDT
- Dish Sterling Project - comparative field test (Bechtel/Cummins/Sterling/PICHTR)
- Solar Drying
  - -Fruits - papaya/pineapple
  - -Coffee beans
  - -Macadamia nuts
  - -Koa Woods
  - -Fish
- IEUP
- OTEC
- Geothermal (power/commercial drying)

HISTORY OF GEOTHERMAL DEVELOPMENT IN HAWAII

- Exploration over past 30 years
- First successful well in 1976
- 3MW demonstration plant 1981
- 500MW estimated in Kilauea east rift zone
- Inter-island power transmission cable proposed
- Several geothermal developers active during past 10 years
- No commercial power plant at present
- 25MW planned to come on line incrementally from ORMAT
- Limited need for energy on Big Island

PROBLEMS AND ISSUES IN GEOTHERMAL DEVELOPMENT

- Environmental issues
  - H_2S, noise, rain forest impact
- Social-cultural issues
  - Anti-development climate
  - Marijuana
  - Hunting-gathering rights
  - Religious freedom
- Technical problems
  - Dry holes
  - Drilling difficulties
  - Problems in completion of wells
- Economic problems
  - Costly delays
  - Unsuccessful wells

LESSONS TO BE LEARNED

- Even when need for change is crystal clear - solutions are not
- Even when you think you have "the" solution technically - you will fail without addressing impact on:
  - Infrastructure in place
  - Social and religious impact
  - Political issues
  - Economics
- Great market potential for renewables in Hawaii and Pacific
  - Guam Micronesian Energy Conference - 5/15-18/91
- Remember - especially in island scenarios it has to be joint effort
  - Government/industry

CONCLUSIONS AND RECOMMENDATIONS TO FACILITATE SOLAR THERMAL ENERGY DEVELOPMENT

- **Government must:**
  - Have clearly stated energy objectives
  - Provide economic incentives to achieve objectives
  - Minimize bureaucratic obstacles
  - Be proactive in anticipating and effectively addressing technical, social, political problems

Conclusions and Recommendations to Facilitate Solar Thermal Energy Development (Cont'd)

- **Industry must:**
  - — Become familiar with complex energy situations in target area
  - — Look for broad geographic opportunities as a starting point, then focus
  - — Consider high cost of land in island scenarios
  - — Production costs must be competitive when all factors are included - technical, social, and environmental
  - — Always consider a demonstration plant
  - — Consolidate technology and experience with shortest possible supply lines, then investigate opportunities on other Pacific islands

OPPORTUNITIES FOR RENEWABLE ENERGY SYSTEMS ON MILITARY BASES

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ABSTRACT

The U.S. Department of Defense (DoD) operates more than 800 military bases, stations, and other installations at locations all over the world. Many of these bases are comparable to small cities with similar energy requirements and environmental issues overlaid with the needs of military operations. The total annual energy consumption for the DoD is more than 1.85 quads costing in excess of $10 billion per year. Over one-third is consumed in the operation of facilities and utilities.

Military base energy managers are facing a rapidly changing world of increasing environmental regulations and constraints. A changing national power picture further exacerbates the situation. Decreasing defense budgets make it increasing difficulties to meet energy requirements and pay the associated energy bills. These increasing military base energy difficulties may provide opportunities for proven, reliable, and cost-effective renewable energy systems.

Military bases are usually situated on large land areas with numerous facilities encompassing large floor areas. They require high levels of energy security and reliability. They have large heating, cooling, domestic hot water, and electrical loads. Energy consumption patterns for most bases are well documented.

Several new pieces of legislation and supporting regulations have emerged that both mandate further reductions in energy consumption and cost for military bases and also urge the use of renewable and alternative energy systems. These documents enhance the opportunities for private investors in renewable energy systems.

This presentation will explain how military bases are comparable to small cities and how they differ, it will describe some of the energy/environmental difficulties currently being faced by military base managers, and then will describe some of the opportunities for employing renewable energy systems to help solve some of these difficulties. It will then describe where some of the opportunity locations are, what types of renewable systems might be used at these locations, and what are some of the obstacles to be overcome in going after these opportunities.

OPPORTUNITIES FOR RENEWABLE ENERGY SYSTEMS ON MILITARY BASES

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Presented at
SOLTECH 91
Hyatt Regency Hotel
Burlingame, California

March 1991

INTRODUCTION

- U.S. DEPARTMENT OF DEFENSE (DOD) OPERATES MORE THAN 800 MILITARY BASES, STATIONS, AND INSTALLATIONS
  - LOCATIONS ALL OVER THE WORLD
  - MANY ARE COMPARABLE TO SMALL CITIES
- TOTAL ANNUAL DOD ENERGY CONSUMPTION IN EXCESS OF 1.85 QUADS
  - APPROXIMATELY 1/3 IS FOR FACILITIES/UTILITY
- TOTAL ANNUAL DOD ENERGY COSTS EXCEED $10 BILLION
  - $3 TO $4 BILLION FOR FACILITY/UTILITY ENERGY COSTS
- MILITARY BASE ENERGY MANAGERS FACING INCREASED DIFFICULTIES
  - AVAILABILITY, DEPENDABILITY, AND QUALITY
  - COSTS
- <u>MANY OPPORTUNITIES FOR RENEWABLE ENERGY SYSTEMS</u>!

A CHANGING WORLD

- ENERGY/ENVIRONMENTAL ISSUES INSEPARABLE IN MANY ASPECTS
  - COAL ⇒ ACID RAIN
  - CFC ⇒ OZONE HOLES
  - GASOLINE ⇒ AIR POLLUTION
  - PETROLEUM TANKERS ⇒ OIL SPILLS
  - FOSSIL FUELS ⇒ CO_2 ⇒ GREENHOUSE EFFECT
- RAPID INCREASE IN AWARENESS, UNDERSTANDING, AND CONCERN FOR THE ENERGY/ENVIRONMENT OF PLANET EARTH
  - GREATER AWARENESS AND CONCERN BY ALL PEOPLE
  - INCREASED ACTIVE RESISTANCE TO ENVIRONMENTAL DEGRADATION
- ENERGY POLICIES NOW BEING DRIVEN MORE STRONGLY BY ENVIRONMENTAL ISSUES
- ENVIRONMENTAL ISSUES COMING TO BEAR VERY STRONGLY ON MILITARY BASE MANAGERS
  - COULD INFLUENCE ENERGY SYSTEM DECISIONS

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CHANGING NATIONAL POWER INDUSTRY

- FUNDAMENTALLY WASTEFUL PROCESS
  - 2/3 OF ALL ENERGY THROWN AWAY
  - ADDITIONAL LOSSES OVER LONG LINES AND SUBSTATIONS
  - INCREASES COST PER UNIT OF USEFUL ENERGY
- FURTHER HAMPERED BY ENVIRONMENTAL CONSTRAINTS
  - EMISSIONS CONTROLS
  - ACID RAIN
  - NEW CLEAN AIR ACT
  - POTENTIAL GREENHOUSE BILL (CARBON TAX)
- PROBLEMS IN MEETING POWER COMMITMENTS
  - BROWN-OUTS ⇒ BLACK-OUTS BY 1995
  - NO NEW POWER PLANT CONSTRUCTION

CHANGING NATIONAL POWER INDUSTRY (CONT'D)

- LONG TERM PROJECTION ⇒ 30 TO 50 YEARS
  - POWER COMPANIES WILL GREATLY DIMINISH POWER GENERATING BUSINESS
  - WILL BECOME MAJOR POWER BROKERS, BUYING AND SELLING POWER AS ON THE COMMODITIES MARKET
  - POWER GENERATION WILL INCREASINGLY BE SUPPLIED BY INDEPENDENT POWER PRODUCERS (IPPs) AND COGENERATORS
  - RENEWABLES TO PROVIDE 30% OF NATION'S POWER BY 2020
- OPPORTUNITIES FOR DOD AND MILITARY BASES
  - EARLY SPONSORSHIP OF IPPs AND COGENERATORS CAN GIVE BASES A LONG TERM COMPETITIVE ADVANTAGE
  - MANY BASES RICH IN RENEWABLE ENERGIES

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MILITARY BASE ENERGY MANAGERS FACING INCREASED DIFFICULTIES

- MANDATED REDUCTION IN ENERGY CONSUMPTION
  - REQUIRES 1% PER YEAR REDUCTION IN FACILITIES/UTILITIES ENERGY FOR 10 YEARS (NOW IN YEAR 6)
  - HAS LED TO RETROFITS, UPGRADES, IMPROVED ENERGY PERFORMANCE
  - MOST EASY CHANGES HAVE ALREADY BEEN ACCOMPLISHED
  - NEXT FOUR YEARS MAY BE MORE DIFFICULT

- MAJOR DROUGHT OVER WESTERN U.S. PAST FOUR YEARS
  - LOW WATER LEVELS IN WESTERN RESERVOIRS
  - WAPA REDUCING POWER ALLOCATIONS TO CUSTOMERS (e.g. MILITARY BASES)
  - BASES MUST BUY MORE POWER FROM COMMERCIAL SOURCES
  - INCREASED COST AND CONSUMPTION OF FOSSIL FUELS

- REPUBLIC OF PHILIPPINES STRUGGLING WITH INCREASED POWER DEMANDS AND UNDERSIZED, AGING GENERATING SYSTEMS
  - CLARK AFB AND SUBIC BAY NAVAL BASE FACED WITH SERIOUS BROWNOUTS
  - CLARK FORCED TO USE PORTABLE GENERATORS AND TO INSTALL 48 MW OF PERMANENT DIESEL GENERATORS
  - INCREASED COST AND GREATER RISK FOR FUEL AVAILABILITY

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MILITARY BASE ENERGY MANAGERS FACING INCREASED DIFFICULTIES (CONT'D)

- QUALITY/RELIABILITY OF ELECTRIC POWER A MATTER OF INCREASING CONCERN
  - MORE OFF-BASE CUSTOMERS AND GREATER LOADS ON POWER GRID
  - FREQUENT INTERRUPTIONS IN POWER AND VARIATIONS IN POWER QUALITY
  - MILITARY ACTIVITIES INCREASINGLY RELIANT ON ELECTRONIC AND COMPUTERIZED SYSTEMS
  - POWER DISRUPTIONS CAUSE GREAT DIFFICULTIES

- SITUATION AT CLARK AFB MAY BE FORERUNNER OF EVENTS TO HAPPEN IN EASTERN U.S.
  - DEMANDS FOR POWER STEADILY INCREASING
  - NUMBER AND CAPACITY OF GENERATING PLANTS DECREASING
  - CROSS-OVER POINT PROJECTED FOR 1995: BROWNOUTS AND BLACKOUTS EXPECTED

- COULD ADVERSELY AFFECT SOME MILITARY BASES
  - MAY SUFFER BROWNOUTS DURING PEAK DEMAND PERIODS
  - MAY BE REQUIRED TO DISCONNECT FROM THE GRID DURING PEAK PERIODS
  - BASES SUBJECTED TO "PEAK POWER ALERTS" ALREADY FEELING THESE ADVERSE EFFECTS

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MILITARY BASE ENERGY MANAGERS FACING INCREASED DIFFICULTIES (CONT'D)

- NEW CLEAN AIR ACT FURTHER EXACERBATES SITUATION
  - REQUIRES FURTHER REDUCTION IN EMISSIONS FROM GENERATING PLANTS
  - MAY MAKE SOME GENERATING PLANTS UNECONOMICAL TO OPERATE
  - APPLIES MOSTLY IN THE EASTERN AND MIDWESTERN U.S., WHERE SHORTAGES ARE ALREADY A CONCERN
- BURNING OF FOSSIL FUELS DUMPS GREAT QUANTITIES OF CO_2 INTO THE ATMOSPHERE
  - CREATES "GREENHOUSE EFFECT" AND WARMING OF EARTH SURFACE (NOT ALL AGREE)
  - COULD LEAD TO "CARBON TAX" IMPOSED ON ALL FOSSIL FUELS (INCREASED COST)
  - CONGRESS COULD MANDATE A PERCENTAGE REDUCTION IN FOSSIL FUEL-DERIVED ENERGY CONSUMED BY MILITARY BASES

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MILITARY BASE ENERGY MANAGERS FACING INCREASED DIFFICULTIES (CONT'D)

- PETROLEUM FUEL SITUATION IN U.S. CONTINUES TO WORSEN
  - NATIONAL CONSUMPTION CONTINUES TO INCREASE
  - U.S. PRODUCTION DECLINING
  - EXPLORATION FOR NEW SOURCES DECLINING
  - U.S. DEPENDENCE ON FOREIGN OIL NEAR 50%
- SITUATION EXACERBATED BY TRANSPORTATION PROBLEMS
  - VALDEZ OIL SPILL 1989
  - CALIFORNIA COAST AND GALVESTON BAY SPILLS 1990
  - CITIZENS ANGERED AND DEMANDING ACTION
  - DOUBLE-HULLED TANKERS AND RESTRICTIONS ON OPERATIONS WILL INCREASE COST
- MILITARY BASES USING PETROLEUM FUELS ARE AT RISK
  - COST INCREASES
  - AVAILABILITY

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MILITARY BASE ENERGY MANAGERS FACING INCREASED DIFFICULTIES (CONT'D)

- INADEQUATE FUEL SUPPLY SYSTEMS POSE PROBLEMS IN SOME REGIONS
  - NATURAL GAS SUPPLY SYSTEM FOR MINNESOTA/NORTH DAKOTA NOT ADEQUATE
  - PROGRAM OF INTERRUPTIBLE SUPPLY ESTABLISHED
  - ATTRACTIVE RATES FOR CUSTOMERS WHO SIGN UP BUT SUBJECT TO INTERRUPTIONS OF SUPPLY ON SHORT NOTICE
  - MUST SHIFT TO ALTERNATIVE FUEL ON NOTIFICATION
  - ALTERNATIVE FUEL CAPABILITY MUST BE MAINTAINED IN READINESS POSTURE — INCREASED O&M COSTS
- CONCERN FOR THE DEPLETION OF THE OZONE LAYER LED TO THE 1986 MONTREAL PROTOCOL
  - MANDATE FREEZE IN PRODUCTION OF CFCs
  - FORCES CHANGE-OVER TO NON-DEPLETION ALTERNATIVES (HCFCs)
  - HCFC REFRIGERATION LESS EFFICIENT — WILL REQUIRE MORE ENERGY AND INCREASED COST FOR EQUAL COOLING

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ENOUGH — THE CASE IS MADE!

- MANY OTHER EXAMPLES COULD BE OFFERED
  - BUT NOT NECESSARY
- IT IS CLEAR — MILITARY BASE ENERGY MANAGERS ARE FACED WITH SERIOUS CHALLENGES NOW AND IN THE FUTURE
  - PROVIDING ADEQUATE ENERGY SERVICES
  - HIGH QUALITY AND FIRM DEPENDABILITY
  - REDUCING COST
- OFFERS OPPORTUNITIES FOR RENEWABLE ENERGY SYSTEMS!

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SUPPORTING DIRECTIVES AND LEGISLATION

- AIR FORCE ENERGY PROGRAM POLICY MEMORANDUM (AFEPPM) 86-6 ESTABLISHED SEVERAL LONG RANGE ENERGY GOALS. ONE IS TO:

  "OBTAIN 5 PERCENT OF TOTAL INSTALLATION ENERGY FROM GEOTHERMAL AND RENEWABLE ENERGY SOURCES BY 1995 (SOLAR HEATING & COOLING, SOLAR ELECTRIC, WIND, BIOMASS, ETC.)"

- STRATEGIC ENVIRONMENTAL R&D PROGRAM (TITLE 10, U.S. CODE, CHAPTER 172) LEGISLATION PASSED IN 1990 TO SUPPORT R&D AND DEMONSTRATION PROJECTS AT DOD AND DOE SITES FOR:
  - ENVIRONMENTALLY SOUND, ENERGY EFFICIENT TECHNOLOGIES
  - GLOBAL CHANGE AND OZONE DEPLETION
  - ENVIRONMENTAL CLEANUP TECHNOLOGIES

- DOD FACILITIES ENERGY POLICY UPDATE (DRAFT – NOV 90) EXPECTED TO ESTABLISH REVISED GOALS TO INCLUDE:

  "USE ALTERNATIVE, RENEWABLE, AND CLEAN ENERGY SOURCES WHEREVER SUCH IS COST EFFECTIVE OVER THE LIFE OF THE FACILITY"

- SENATE BILL 341 (NEW NATIONAL ENERGY POLICY BILL) CONTAINS PROVISIONS FOR

  "DIESEL FUEL OIL DISPLACEMENT BY PHOTOVOLTAIC AND WIND ENERGY SYSTEMS"

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REDUCED CONSUMPTION OF PETROLEUM PRODUCTS

- A MAJOR DOD GOAL — TO REDUCE FACILITY/UTILITY CONSUMPTION OF LIQUID PETROLEUM PRODUCTS
  - REDUCE IMPORTS
  - ENSURE AVAILABILITY
  - REDUCE COSTS

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THIRD PARTY FINANCING AND OPERATIONS

- <u>AFEPPM 85-1</u>: STATES THAT THIRD PARTY FINANCING BE "VIGOROUSLY" PURSUED ON A COMPETITIVE BASIS WITH MCP TO IMPROVED ENERGY SECURITY AND EFFICIENCY
  - MANDATES LIFE-CYCLE COST ASSESSMENT OF THIRD PARTY VERSUS MCP
- OPENS DOORS FOR THIRD PARTY FINANCING, CONSTRUCTION, AND OPERATION OF MILITARY BASE ENERGY SYSTEMS
- CAN LOCATE PROJECTS ON MILITARY BASES IN OPPOSITION TO FRANCHISED UTILITY
- CONTRACTS MUST BE WRITTEN TO PROTECT THE GOVERNMENT
  - NO LONG TERM OBLIGATION OF GOVERNMENT

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MILITARY INSTALLATIONS COMPARABLE TO SMALL CITIES

- LARGE LAND AREAS — OFTEN REMOTE
- NUMEROUS FACILITIES — LARGE FLOOR AREAS
  - BARRACKS, DINING HALLS, CLASSROOMS
  - OFFICE BUILDINGS AND ADMINISTRATION COMPLEXES
  - OPERATIONS BUILDING WITH SPECIALIZED EQUIPMENT
- REQUIREMENT FOR HIGH ENERGY SECURITY AND RELIABILITY
  - MUST BE AVAILABLE WHEN NEEDED

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MILITARY BASE FACILITY/UTILITY ENERGY PATTERNS

- LARGE HEATING AND DOMESTIC HOT WATER LOADS
  - USUALLY PROVIDED BY NATURAL GAS OR COAL (CONUS)
  - SOME ONBASE STEAM PLANTS AND STEAM DISTRIBUTION SYSTEMS
  - NATURAL GAS TO MANY INDIVIDUAL BUILDINGS
- LARGE ELECTRICAL LOADS
  - MOST PURCHASED FROM LOCAL UTILITY COMPANIES
  - 15 TO 20 MW FOR AVERAGE BASE
  - 40 TO 60 MW FOR SOME LARGE BASES
  - FEW ON-BASE GENERATING PLANTS
  - DIESEL BACKUP GENERATORS FOR CRITICAL FACILITIES

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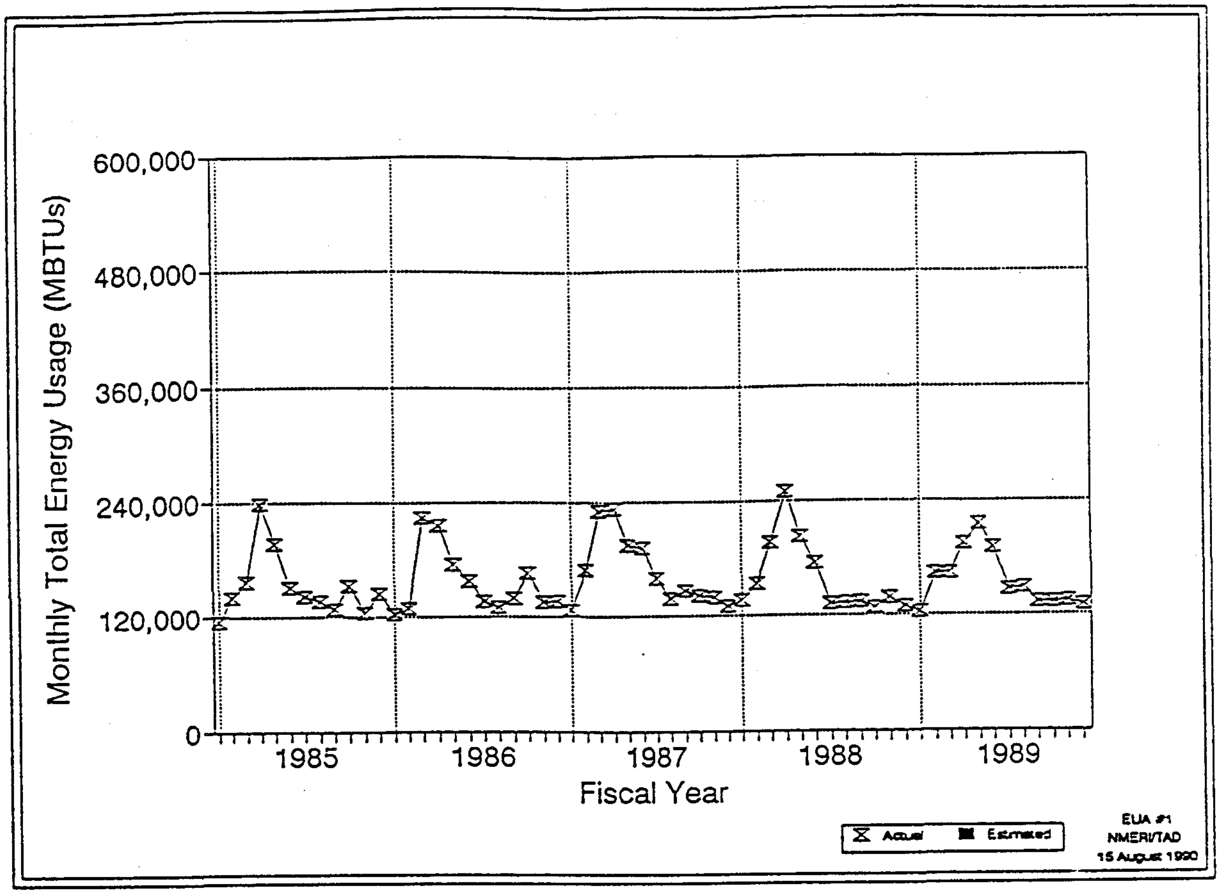
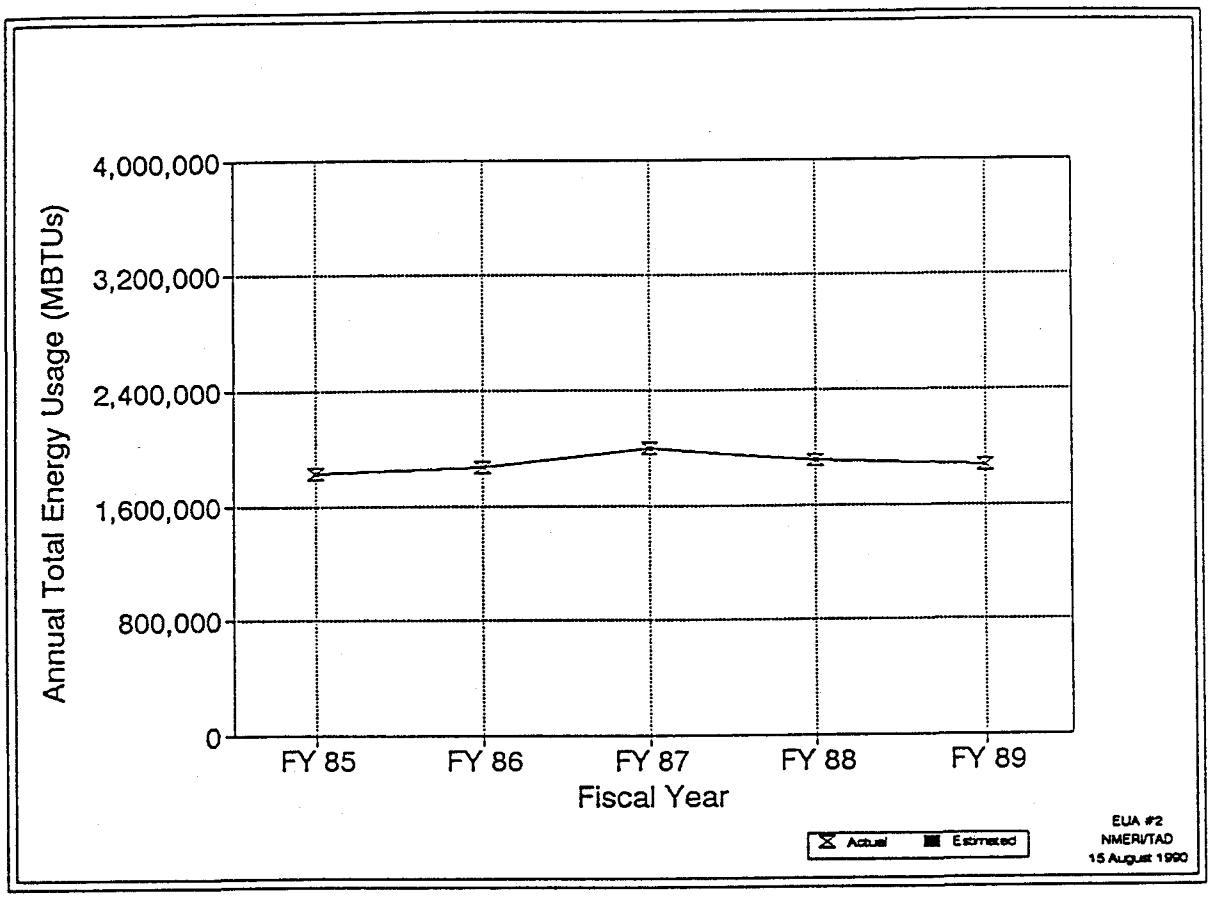
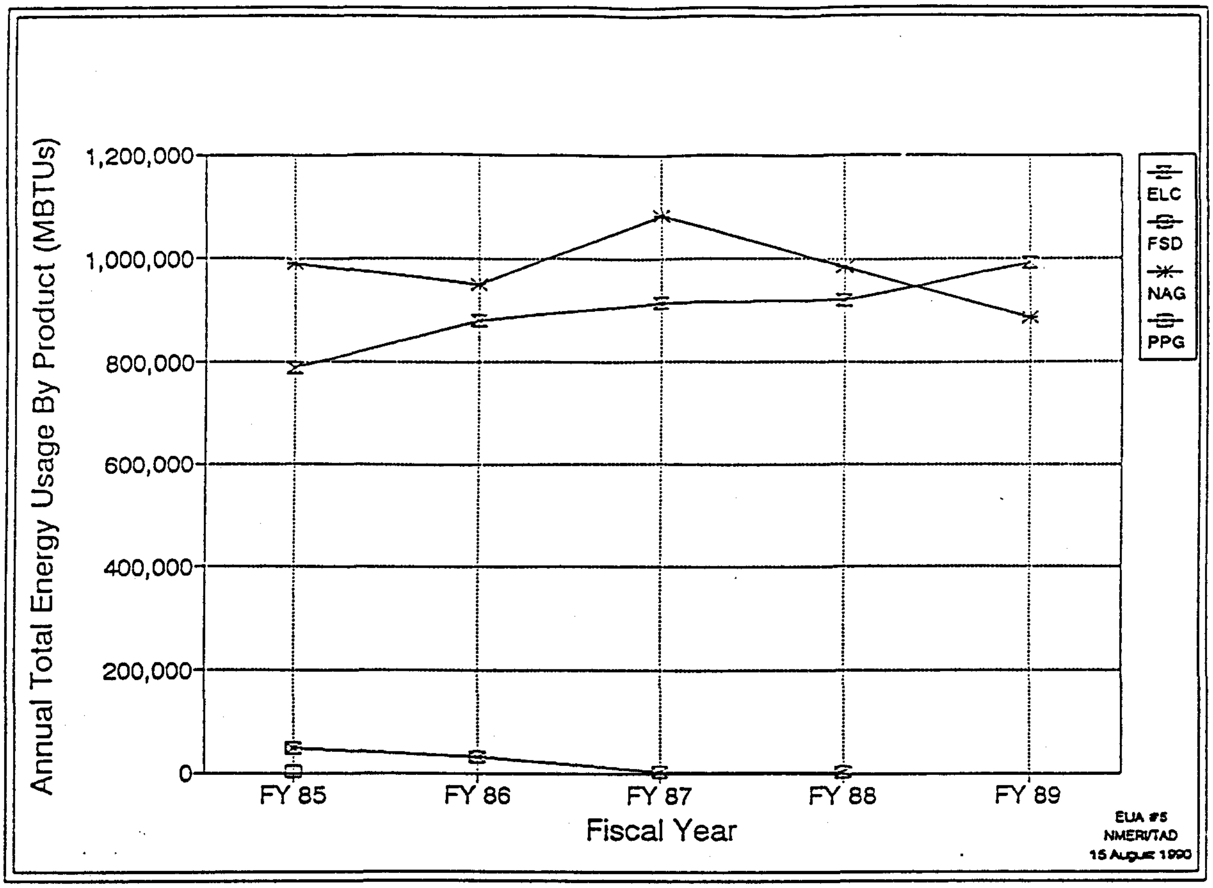
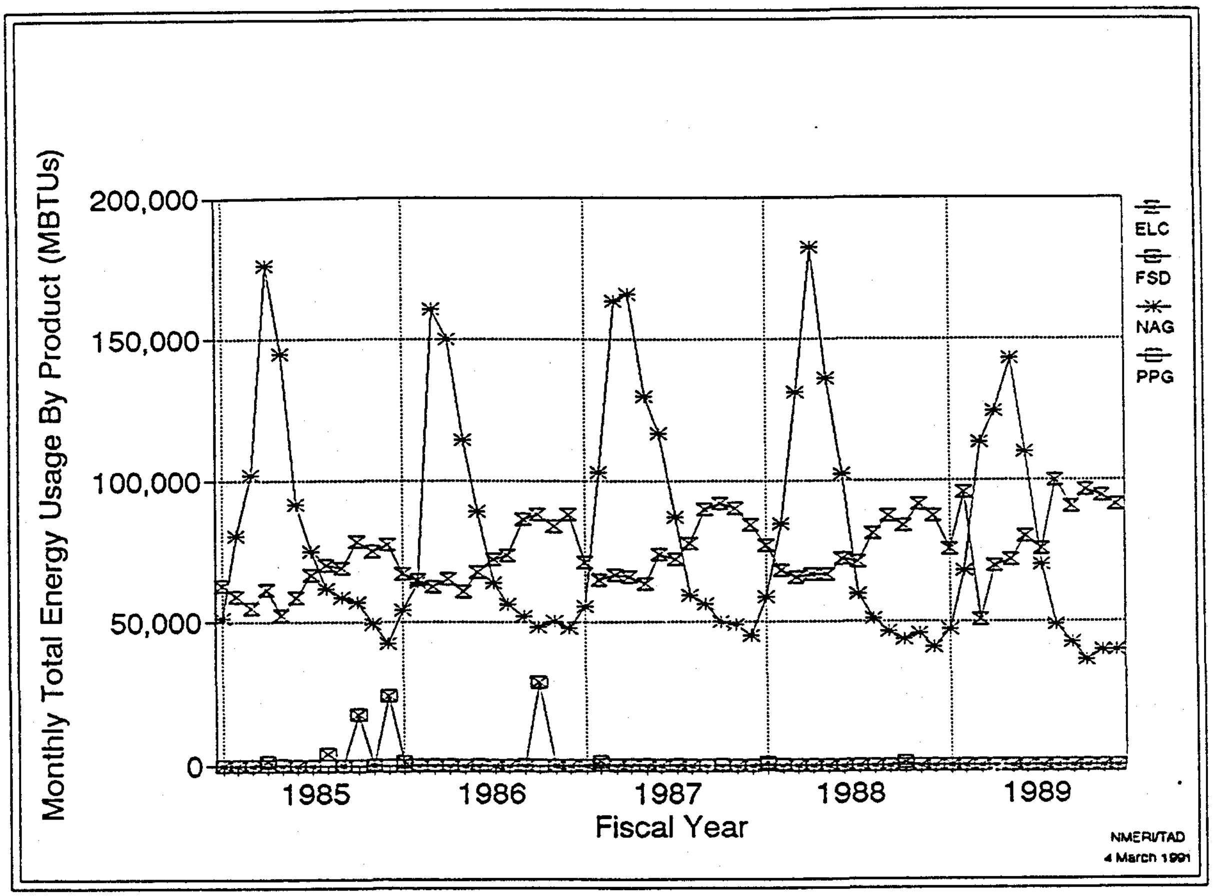


600,000
480,000
360,000
240,000
120,000
0
Monthly Total Energy Usage (MBTUs)
1985
1986
1987
1988
1989
Fiscal Year
Actual
Estimated
EUA #1
NMERI/TAD
15 August 1990



4,000,000
3,200,000
2,400,000
1,600,000
800,000
0
Annual Total Energy Usage (MBTUs)
FY 85
FY 86
FY 87
FY 88
FY 89
Fiscal Year
Actual
Estimated
EUA #2
NMERI/TAD
15 August 1990


1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Annual Total Energy Usage By Product (MBTUs)
FY 85
FY 86
FY 87
FY 88
FY 89
Fiscal Year
ELC
FSD
NAG
PPG
EUA #5
NMERI/TAD
15 August 1990


200,000
150,000
100,000
50,000
0
Monthly Total Energy Usage By Product (MBTUs)
1985
1986
1987
1988
1989
Fiscal Year
ELC
FSD
NAG
PPG
NMERI/TAD
4 March 1991

LOCATIONS FOR CANDIDATE BASES

- MANY LOCATIONS IN SEVERAL REGIONS CAN PROVIDE SOLTECH OPPORTUNITIES
- SOUTHERN AND MIDWEST REGIONS PROVIDE GREATEST OPPORTUNITIES FOR SOLAR SYSTEMS
- WESTERN PLAINS AND WEST COAST REGIONS OFFER GREATEST OPPORTUNITIES FOR WIND SYSTEMS
- PACIFIC RIM AND ALASKA OFFER BOTH
  - EXTREMELY DEPENDENT ON FUEL OIL
  - ELECTRICITY PRODUCED MOSTLY FROM FUEL OIL
  - ASSOCIATED HIGH COSTS AND CONCERNS FOR AVAILABILITY
  - REFRIGERATED AIR AND DOMESTIC HOT WATER PRODUCED FROM ELECTRICITY

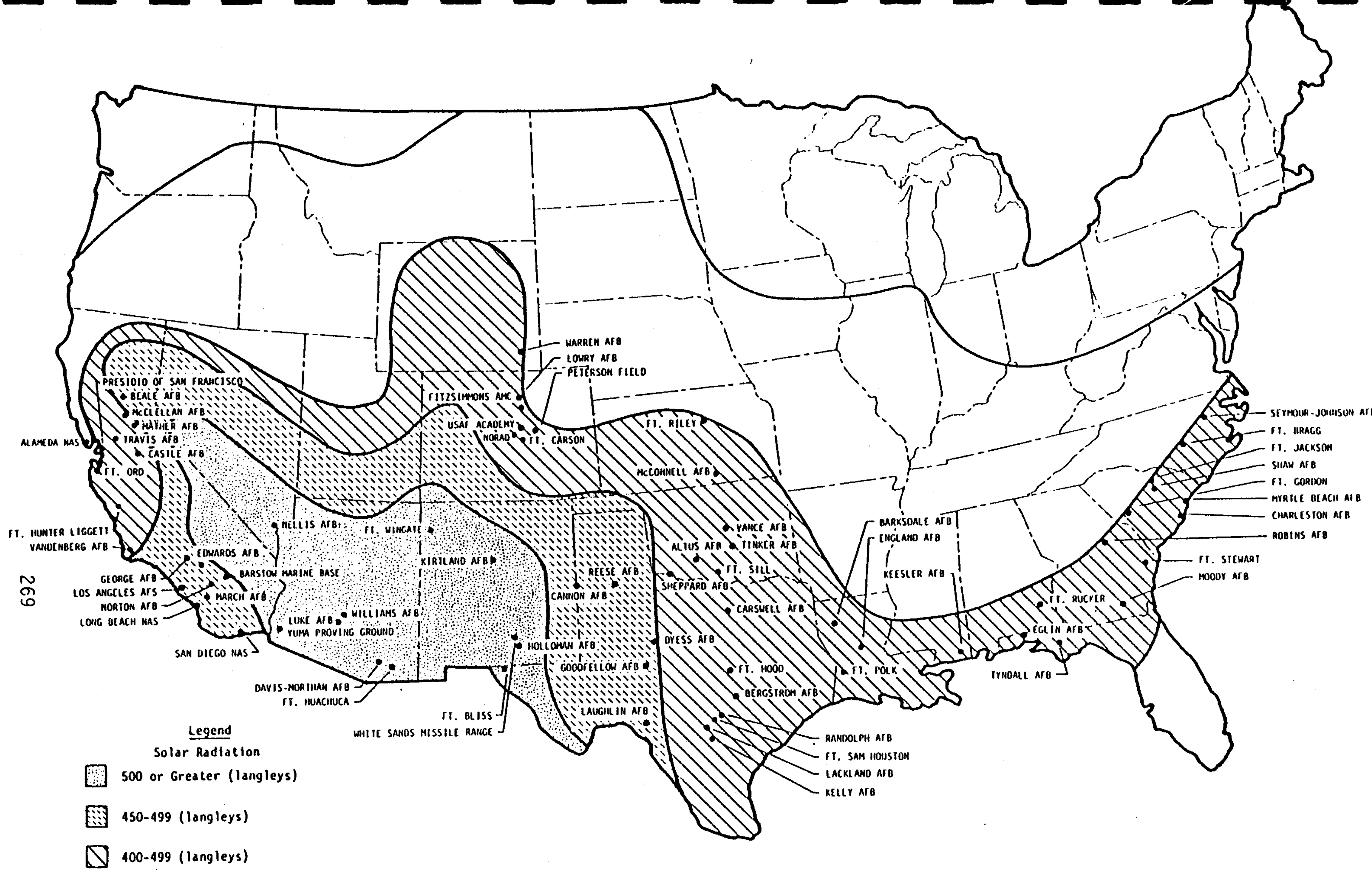


FIGURE 4. MILITARY INSTALLATIONS LOCATED IN REGIONS WITH HIGH LEVELS OF SOLAR FLUX

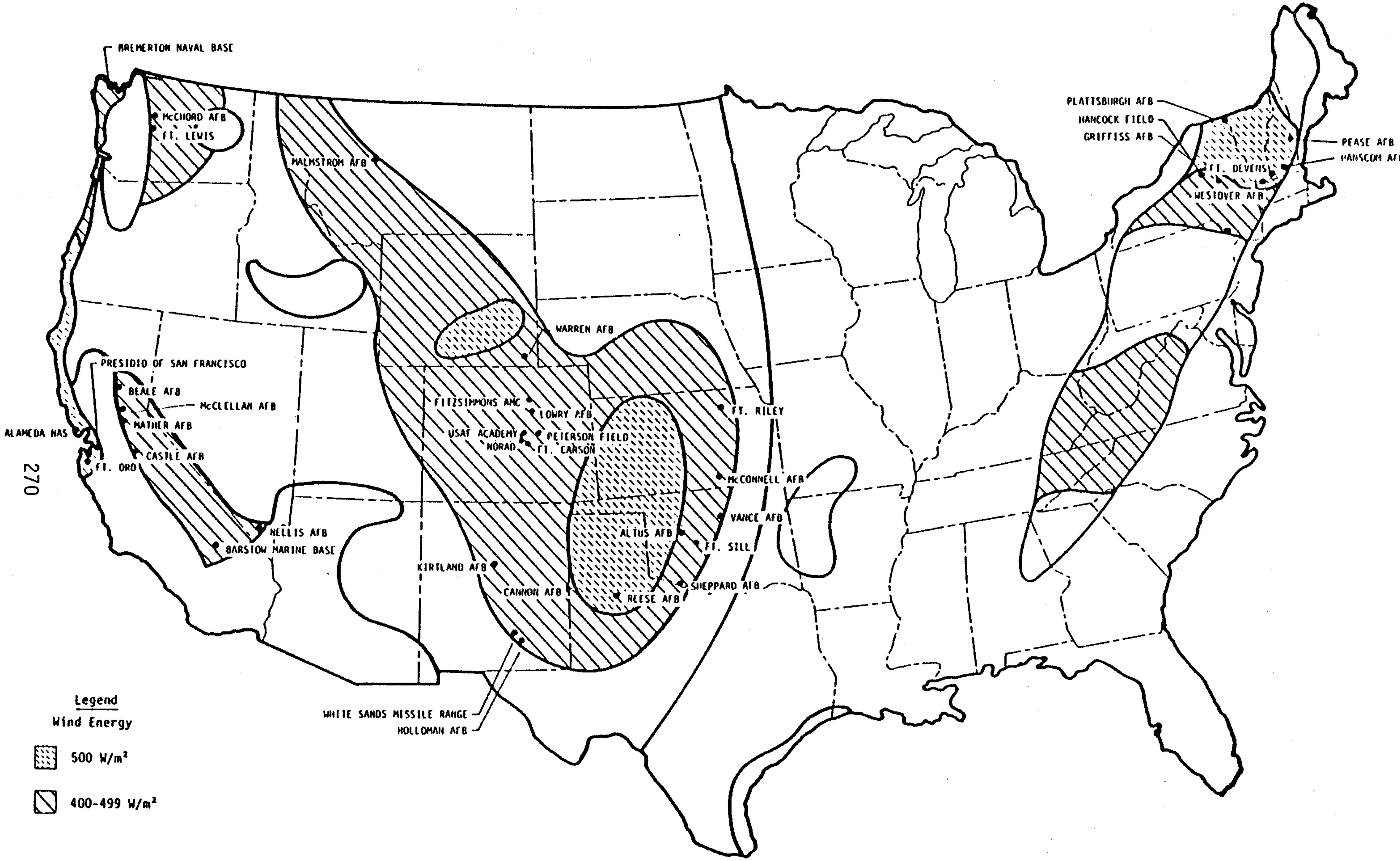


FIGURE 7. MILITARY INSTALLATIONS LOCATED IN REGIONS WITH GOOD WIND ENERGY

POTENTIAL TYPES OF SOLTECH SYSTEM OPPORTUNITIES

- SOLAR THERMAL SYSTEMS
  - SINGLE FAMILY DOMESTIC HOT WATER
  - MULTIPLE-UNIT (BARRACKS) DOMESTIC HOT WATER
  - SOLAR FACILITY HEATING (STEAM) AND COOLING (STEAM — ABSORPTION CHILLER)
  - SOLAR PROCESS STEAM

- SOLAR THERMAL ELECTRIC SYSTEMS
  - PARABOLIC TROUGH OR DISH SOLAR STEAM TURBINE
  - MOLTEN SALT CENTRAL SOLAR RECEIVER/STEAM TURBINE

- SOLAR THERMAL ELECTRIC COGENERATION SYSTEMS
  - ABOVE SOLAR THERMAL ELECTRIC BUT USE LOW GRADE STEAM FOR PROCESS STEAM OR COOLING

- SOLAR PHOTOVOLTAIC SYSTEMS
  - SMALLER, REMOTE APPLICATIONS

- WIND ENERGY SYSTEMS
  - 100 TO 600 kW
  - HAWT
  - VAWT

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NEED PROVEN SYSTEMS

- BAD RECOLLECTIONS OF 1970s DEMONSTRATION PROJECTS
- WANT DEPENDABLE PROVEN SYSTEMS
- LARGE CONCERN FOR O&M DIFFICULTIES/COSTS
  - MUST SUGGEST HOW O&M TO BE ACCOMPLISHED AND COSTS
- SOME EXCEPTIONS FOR SPECIAL DEMONSTRATION PROJECTS

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OBSTACLES TO OVERCOME

- ENTRENCHED PERSPECTIVE OF DOD DESIGN/CONSTRUCT AGENCIES AND ASSOCIATED A&E CONTRACTORS
- MILITARY PERSONNEL TOO BUSY TO UNDERTAKE TIME-CONSUMING PROJECT
- MISINFORMATION
  - $12,500 SINGLE FAMILY SOLAR SYSTEM
  - COGENERATION DOES NOT WORK
- ADVERSE PUBLICITY FROM FAILED 1970's DEMONSTRATION PROJECTS
- OPPOSITION FROM UTILITY INDUSTRIES
- CONCERN OVER O&M FOR RENEWABLE ENERGY SYSTEMS

NEW MEXICO
ENGINEERING
RESEARCH INSTITUTE

HOW SOLAR ELECTRIC TECHNOLOGY MAY HELP ALLEVIATE SEVERE ELECTRICITY SHORTAGES IN THE DOMINICAN REPUBLIC

by Ellis Perez
Solar Uno

DEFICIT IN SUPPLY AND DEMAND OF ELECTRICITY IN THE DOMINICAN REPUBLIC

YEAR	SUPPLY MW	DEMAND MW	DEFICIT MW
1980	304.4	462.0	-157.6
1981	322.7	475.0	-152.3
1982	329.8	584.0	-254.2
1983	262.9	546.0	-183.1
1984	370.7	565.0	-194.3
1985	386.4	596.0	-209.6
1986	415.3	650.0	-234.7
1987	421.6	685.0	-263.4
1988	423.7	691.0	-267.3
1989	418.6	662.0	-243.4
1990	365.4	616.0	-250.6

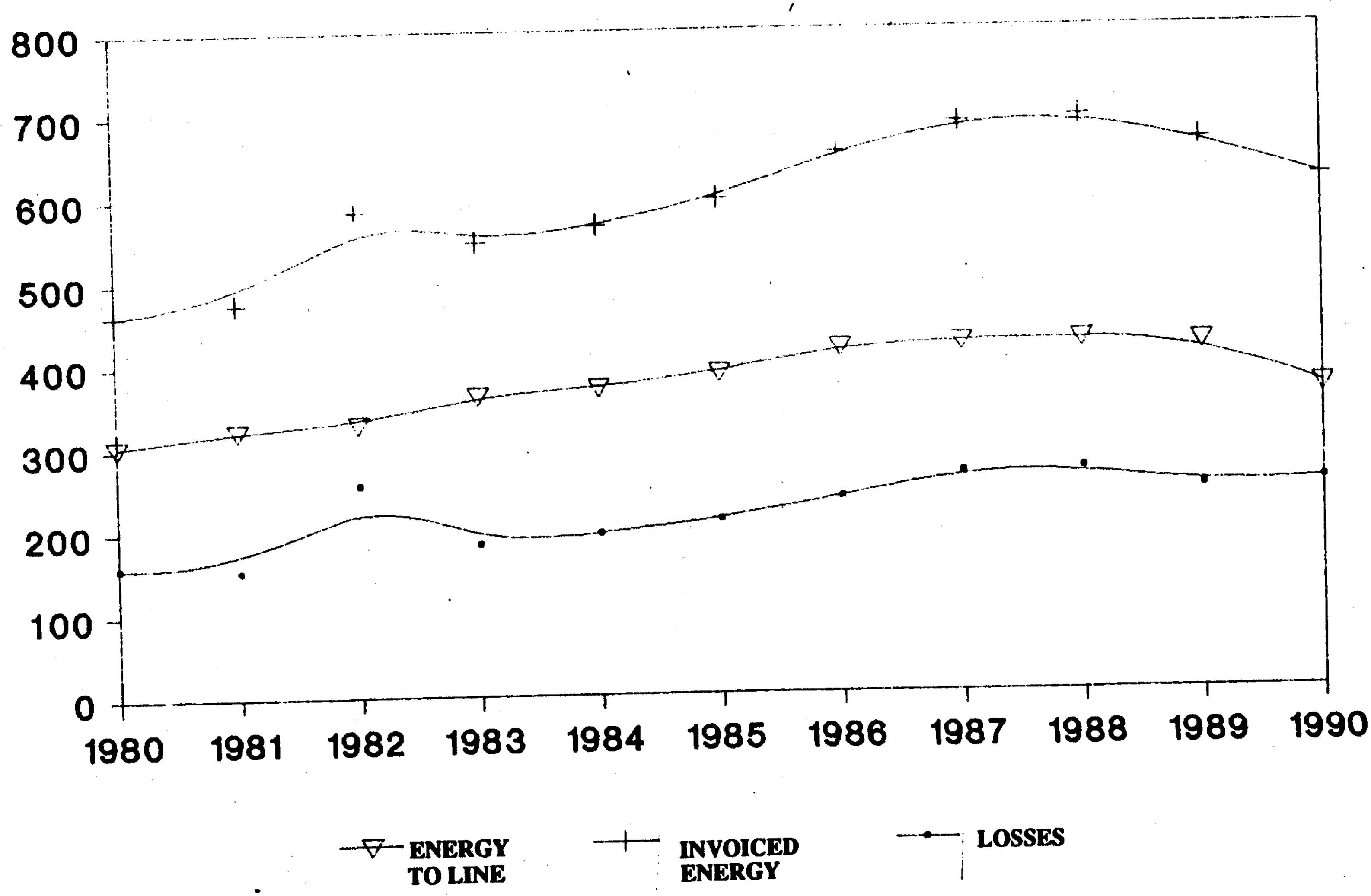
SOURCE - C.D.E.

LOSSES IN ENERGY DISTRIBUTION IN THE DOMINICAN REPUBLIC.

YEAR	ENERGY SENT TO LINE	INVOICED ENERGY	LOSSES	%
1980	2629.8	1913.6	716.2	27.2
1981	2787.7	2084.6	703.1	25.2
1982	2849.1	1889.3	959.8	33.7
1983	3135.4	1962.9	1172.5	37.4
1984	3202.4	2210.2	992.2	31.0
1985	3338.2	2315.2	1023.0	30.6
1986	3588.4	2423.4	1165.0	32.5
1987	3643.0	2710.1	932.9	25.6
1988	3660.6	2618.3	1042.3	28.5
1989	3616.3	2398.4	1217.9	33.7
1990	1637.3	1122.1	515.2	31.5

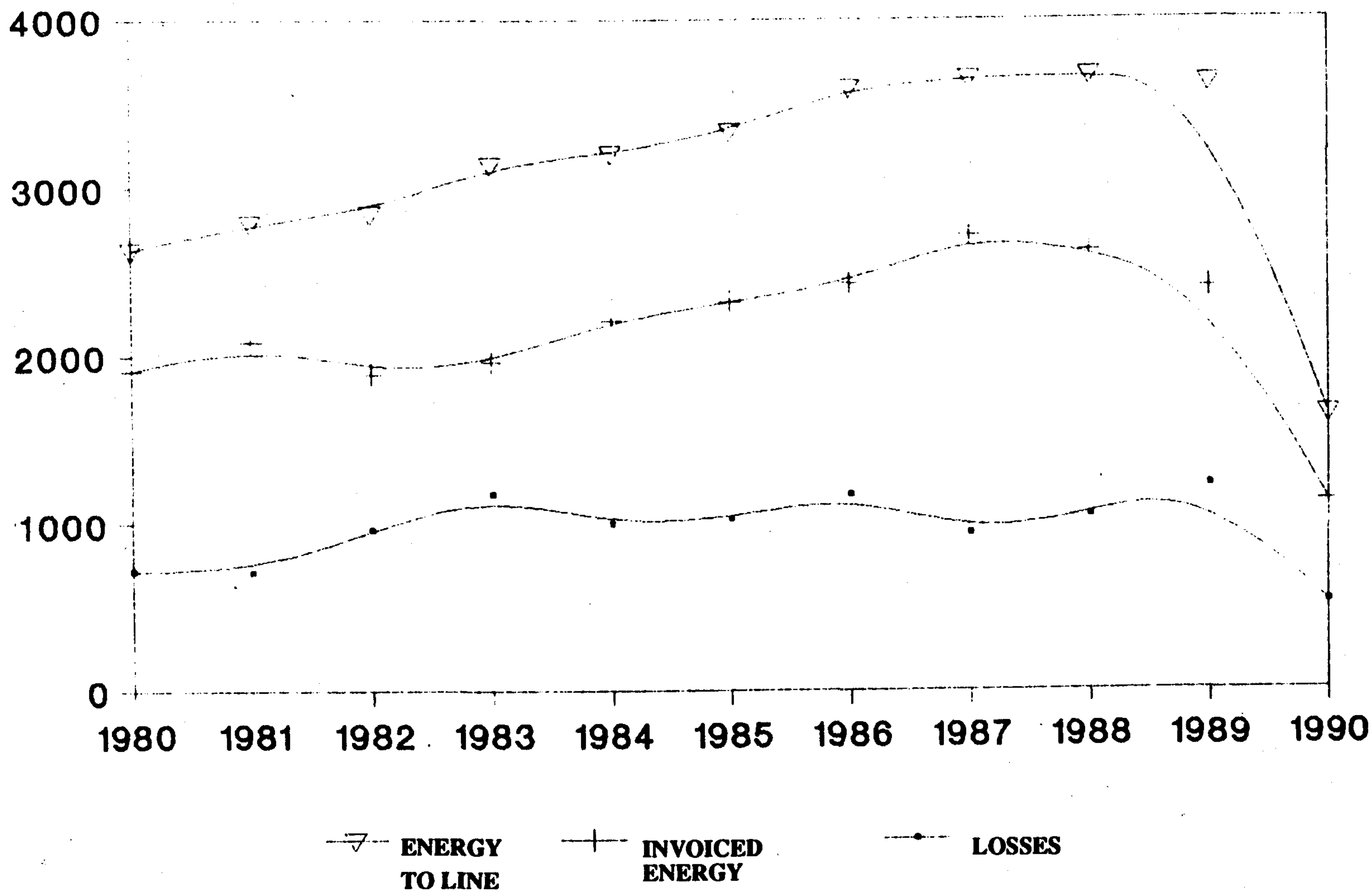
SOURCE - C.D.E.

LOSSES IN ELECTRICAL ENERGY DISTRIBUTION IN THE D. R.



DEFICITS, SUPPLY AND DEMAND OF ELECTRICAL ENERGY IN THE D. R.

1980 - 1990



OPPORTUNITIES FOR SOLAR THERMAL ELECTRIC TECHNOLOGY IN NEVADA

by Rose McKinney-James
Public Service Commission of Nevada

After five months, three hearings, two expert panel exchanges, and two consumer sessions, the Nevada Public Service Commission unanimously adopted a new rule designed to recognize and quantify environmental externalities. The rule sets forth a mechanism for the commission to provide preference to those sources of electricity which are kindest to the environment while providing some direct economic benefit to the state of Nevada.

This rule opens the door to the introduction of solar power as a viable and competitive participant in the electric resource mix of Nevada electric utilities. It may well expand the use of geothermal electricity generation and the exploration of wind power in the state.

The promulgation of this regulation came as a result of state legislation which became effective in October 1989. This measure required the commission to establish a preference to those sources of electricity generation which "provide the greatest economic and environmental benefits to the state".

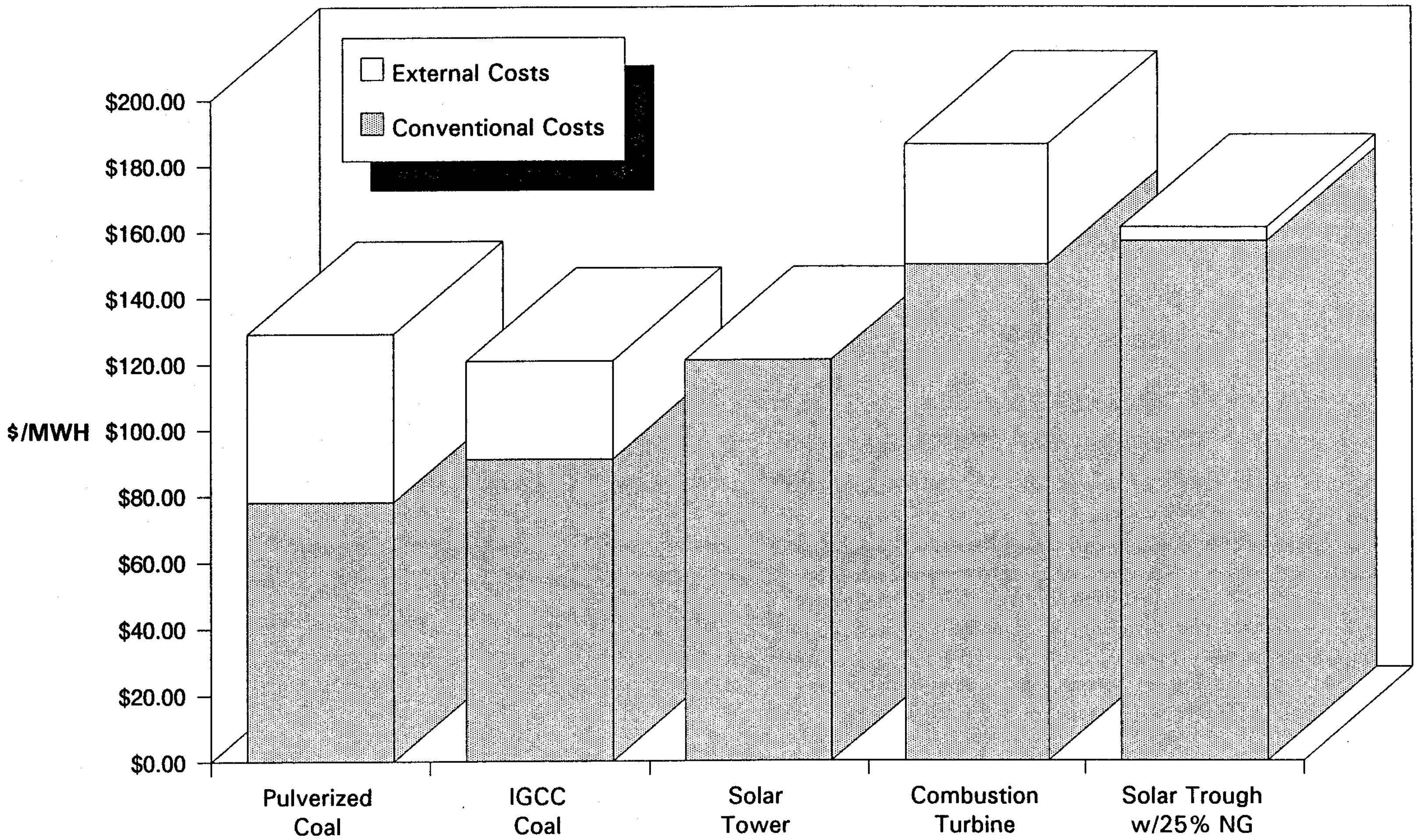
LUZ International recognized as the nations leading solar company is presently in negotiations with Nevada Power Company to construct a 120 megawatt facility in southern Nevada.

The climate for the use of solar in Nevada is very positive from both the political and regulatory perspective. However, many questions will need to be answered before the commission can fully embrace solar as an electric generation option. We will need to determine the extent to which the use of a natural gas back-up will increase the cost to ratepayers; the extent to which the use of natural gas may increase rather than decrease environmental damage impacts on land use, e.g., the desert tortoise and, the impact on water use. The future of the water supply in fast growing southern Nevada is probably <u>the</u> public policy issue for the 1990's.

NEVADA VALUATION OF ENVIRONMENTAL COSTS

Pollutant	Valuation (1990 dollars/lb)
Carbon Dioxide (CO_2)	0.011
Methane (CH_4)	0.11
Nitrous Oxide (N_2O)	2.07
Nitrogen Oxides (NO_x)	3.4
Sulfur Oxides (SO_x)	0.78
Volatile Organic Compounds (VOC)	0.59
Carbon Monoxide (CO)	
Ambient Air Quality +	0.43
Global Warming Contribution	0.03
Total	0.46
Total Suspended Paticulates / Particulate Matter (Diam < 10mm) TSP/PM_{10}	2.09
Hydrogen Sulfide (H_2S)	NA
NH_3	0
Water Impact	Site Specific (Determined by Utility)
Land Use	Site Specific (Determined by Utility)

IMPACT OF ENVIRONMENTAL EXTERNALITIES ON THE EVALUATION OF SUPPLY OPTIONS



RESIDUAL ENVIRONMENTAL COSTS

TYPE OF POWER PLANT	VALUE SET IN NEW YORK	VALUE SET IN MASSACHUSSETTS	VALUE SET IN NEVADA	VALUE IN PACE STUDY
COAL-FIRED PLANT MEETING NSPS	1.4c/Kwh	4.4c/Kwh	4.3c/Kwh	4.5c/Kwh
COAL FLUIDIZED BED		3.0c/Kwh		3.3c/Kwh
NATURAL GAS COMBINED CYCLE		1.1c/Kwh	2.2c/Kwh	1.1c/Kwh
GEOTHERMAL			0.2c/Kwh	
SOLAR THERMAL WITH NATURAL GAS BACKUP (35% LOAD FACTOR)			0.5c/Kwh	0 to 0.4c/Kwh

IMPACT OF ENVIRONMENTAL EXTERNALITIES ON THE EVALUATION OF SUPPLY OPTIONS

	Pulverized Coal w/FGD	IGCC Coal	Solar Tower Central Receiver	Combustion Turbine NG	Solar Trough w/25% NG Backup & LN
Capacity Factor	80%	80%	63%	10%	35%
Conventional Costs in $/MWH					
Fixed	36.00	42.00	110.00	58.00	135.00
Variable	42.00	49.00	11.00	92.00	22.00
Total Conventional Costs	$78.00	$91.00	$121.00	$150.00	$157.00
Emissions Factors in lbs/MWH					
NOx	6	1.9	0	5.152	0.085
SOx	6	3.1	0	0.008	0.00175
TSP	0.3	0.03	0	0.174	0.008
CO	0.23	0.09	0	1.434	0.105
VOC	0.038	0.03	0	0.16	0.0035
CO2	2240	1840	0	1560	327.5
CH4	0.014	0.014	0	0.16	0.0005
N2O	0.306	0.302	0	0.24	0.0775
Valuation of Environmental Externalities Costs in $/MWH					
NOx @ $3.40/lb	20.400	6.460	0.000	17.517	0.289
SOx @ $0.78/lb	4.680	2.418	0.000	0.006	0.001
TSP @ $2.09/lb	0.627	0.063	0.000	0.364	0.017
CO @ $0.46/lb	0.106	0.041	0.000	0.660	0.048
VOC @ $0.59/lb	0.022	0.018	0.000	0.094	0.002
CO2 @ $.011/lb	24.640	20.240	0.000	17.160	3.603
CH4 @ $0.11/lb	0.002	0.002	0.000	0.018	0.000
N2O @ $2.07/lb	0.633	0.625	0.000	0.497	0.160
Total Environmental Costs	$51.11	$29.87	$0.00	$36.32	$4.12
Total Cost	$129.11	$120.87	$121.00	$186.32	$161.12

BEFORE THE PUBLIC SERVICE COMMISSION OF NEVADA

In Re rulemaking regarding resource)
planning changes pursuant to SB 497.)
) Docket No. 89-752

At a general session of the Public Service Commission of Nevada, held at its offices in Carson City, Nevada, January 22, 1991.

PRESENT: Chairman Thomas E. Stephens
Commissioner Stephen Wiel
Commissioner Jo Ann Kelly
Commissioner Michael A. Pitlock
Commissioner Rose McKinney-James
Secretary William H. Vance

ORDER

The Public Service Commission of Nevada ("Commission") makes the following findings of fact and conclusions of law:

1. In July 1989, the Commission opened a rulemaking docket to adopt regulations relating to the resource plans of electric utilities with annual operating revenue in Nevada of $2,500,000 or more.
2. The matter has been designated as Docket No. 89-752.
3. Nevada Revised Statute ("NRS") 704.746, as amended in October 1989, directs the Commission to adopt regulations which determine the level of preference to be given to those measures and sources of supply that (1) provide the greatest economic and environmental benefits to the State, (2) are consistent with the provisions of NRS 704.746, and (3) provide levels of service that are adequate and reliable.
4. On May 1, 1990, the Commission issued a Notice of Workshop and Request for Comments Regarding the Development of Proposed Regulations.
5. The Commission received written comments from the Attorney General's Office of Advocate for Customers of Public Utilities

("OCA"), Sierra Pacific Power Company ("SPPC"), the State of Nevada's Commission on Economic Development ("CED"), Nevada Power Company ("NPC"), the State of Nevada's Office of Community Services ("NOCS"), California Energy Company, LUZ Development and Finance Corporation and its parent company LUZ International ("LUZ"), Bonneville Pacific Corporation ("Bonneville"), Ormat Energy Systems, Inc. ("Ormat"), the Clark County Health District and the Regulatory Operations Staff of the Commission ("Staff").

6. The workshop was held in Las Vegas on May 31, 1990.

7. On July 10, 1990, the Commission issued a Notice of Workshop for an "experts panel workshop".

8. On July 23, 1990, the Commission issued a Corrected Notice of Workshop.

9. The "experts panel workshop" was held in Carson City on August 7, 8 and 15, 1990.

10. On August 20, 1990, the Commission issued a Notice of Workshop.

11. A workshop was held in Las Vegas on September 21, 1990.

12. On October 2, 1990, the Commission issued a Notice of Consumer Session.

13. Consumer sessions were held in Las Vegas on October 25, 1990 and in Reno on October 29, 1990.

14. At a regularly scheduled agenda meeting on November 19, 1990, the Commission voted to issue a proposed regulation for this docket.

15. On November 21, 1990, the Commission issued a Notice of Intent to Adopt Regulation, Request for Comments and Notice of Hearing ("Notice of Intent")

16. In addition to inviting comments from interested persons on all aspects of the proposed rule, the Notice of Intent specifically solicited comments on the following issues:

a. whether the final rule should retain present worth of revenue requirement ("PWRR") as the primary selection criterion, establish present worth of societal costs ("PWSC") as the primary selection criterion or leave the issue for determination by the Commission in each resource plan?

b. whether a party other than the company has the burden to establish the PWSC for an option?

c. how the quantification of the environmental costs and economic benefits of demand side programs should be utilized in establishing the PWRR or PWSC of an option?

d. whether the PWSC associated with a power purchase from an existing plant should be treated differently than a plant to be constructed?

e. whether the Commission should include language (in table form) in its final Order (and not within the rule itself) which provides values for pollutant emission factors and environmental costs which shall be used by all affected utility companies from the date of that Order until the Commission's decision in each company's next resource plan.

17. The Commission received comments from Staff, OCA, LUZ and California Energy Company, Inc., Sierra Pacific Resources, Ormat, NPC, SPPC, American Wind Association, Dr. Timothy Duane, Clark County Health District and Les Simmons.

18. The hearing commenced on January 8, 1991, and concluded on January 9, 1991.

19. At the beginning of the hearing, five public witnesses provided comments.

20. Participating at the hearing were Staff, OCA, Sierra Pacific Resources, SPPC, NPC, LUZ, Ormat, California Energy Company, Clark County Health District and the Utility Shareholder's Association.
21. The record for this docket includes 1,718 pages of transcript and 60 exhibits.
22. The workshops and hearing were noticed in conformance with NRS 233B.
23. Attached to the Notice of Intent were three tables reflecting values of emission factors and environmental costs.
24. At the hearing, there was significant support for eliminating Table 3 and revising Tables 1 and 2.
25. The values of emission factors and environmental costs listed in the attached Tables 1 and 2 shall be used by all affected utility companies as default values from the date of this Order until the Commission's decision in each company's next resource plan.
26. The concept of "societal dispatch" was discussed at the hearing. NPC volunteered to provide such an analysis in its next resource plan.

Therefore, it is ORDERED that:

1. The regulations, as attached hereto, are hereby ADOPTED as the final rule. By this reference, said rule is incorporated in the instant Order.
2. The attached Tables 1 and 2 are hereby incorporated in the instant Order.
3. The values of emission factors and environmental costs listed in the attached Tables 1 and 2 shall be used by all affected utility companies as default values from the date of this Order until the Commission's decision in each company's next resource plan.

4. The Commission retains jurisdiction for the purpose of correcting any errors which may have occurred in the drafting or issuance of this Order.

By the Commission,

THOMAS E. STEPHENS, Chairman

STEPHEN WIEL, Commissioner

JO ANN KELLY, Commissioner

MICHAEL A. PITLOCK, Commissioner

ROSE McKINNEY-JAMES, Commissioner

Attest:

WILLIAM H. VANCE, Secretary

Dated: Carson City, Nevada
2/1/91

(SEAL)

TABLE 1

1/11/91

Electric Facilities Emissions Factors and Water Use

New Utility Facilities

	Emissions (lbs/MMBtu in)										Water Use (gals per MMBtu in)
	NOx	SOx	TSP	CO	VOC	CO2	CH4	N2O	H2S	NH3	
Baseload											
a. Combined Cycle NG	0.3933	0.0006	0.001	0.021	0.033	117	0.0019	0.0078	NA	NA	17.5
b. Combined Cycle NG w/SWI	0.0787	0.0006	0.001	0.021	0.033	117	0.0019	0.0078	NA	NA	17.5
c. Combined Cycle NG w/SWI + SCR	0.0283	0.0006	0.001	0.021	0.033	117	0.0019	0.0078	NA	0.037	17.5
a. Combined Cycle Distillate Oil	0.5	0.315	0.001	0.018	0.0165	163	0.0016	0.0325	NA	NA	17.5
b. Combined Cycle Distillate Oil w/SCR	0.1	0.315	0.001	0.018	0.0165	163	0.0016	0.0325	NA	0.039	17.5
3a. Combined Cycle Residual Oil	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
a. Coal, Pulverized w/scrubbers	0.6	0.6	0.03	0.024	0.004	238	0.0015	0.0325	NA	NA	48.4
. Coal, Atmospheric Fluidized Bed	0.5	0.6	0.01	0.15	0.0028	238	0.0015	0.0325	NA	NA	1590
6a. Coal, Integrated Gasificaton Comb. Cycle	0.20	0.33	0.003	0.01	0.003	198	0.0015	0.0325	NA	NA	NA
a. Geothermal Flashed steam w/injection	NA	NA	NA	NA	NA	0.03	1E-05	NA	0.00166	NA	55.6
. Solar, Thermal	0	0	0	0	0	0	0	0	0	0	69
b. NG, Boiler back-up unit	0.150	0.0006	0.00290	0.038	0.0013	119	0.0002	0.028	NA	NA	93
. NG, Boiler back-up unit with LNB	0.031	0.0006	0.0029	0.038	0.0013	119	0.0002	0.028	NA	NA	93
. NG, Boiler back-up unit with LNB + SCR	0.012	0.0006	0.0029	0.038	0.0013	119	0.0002	0.028	NA	NA	93
9a. Solar, Photovoltaic	0	0	0	0	0	0	0	0	0	0	0
10a. MSW, Steam Boiler	0.308	0.38	0.4700	0.93	0.0300	165	0.001	0.033	NA	NA	NA
b. MSW, Steam Boiler w/FFB	0.308	0.38	0.00470	0.93	0.0300	165	0.001	0.033	NA	NA	NA
11a. Wood, Steam Boiler	0.155	0.0083	0.4862	0.221	0.0773	212	0.033	0.033	NA	NA	NA
b. Wood, Steam Boiler w/FFB	0.155	0.0083	0.00486	0.221	0.0773	212	0.033	0.033	NA	NA	NA
a. Wind	0	0	0	0	0	0	0	0	0	0	0
13a. Small Hydroelectric	0	0	0	0	0	0	0	0	0	0	0
14a. Purchases	Check source note.										
Peakers											
1a. Combustion Turbine NG	0.3933	0.0006	0.0133	0.1095	0.012	119	0.012	0.018	NA	NA	0.03
. Combustion Turbine NG w/SWI	0.0787	0.0006	0.0133	0.1095	0.012	119	0.012	0.018	NA	NA	0.03
c. Combustion Turbine NG w/SWI + SCR	0.0283	0.0006	0.0133	0.1095	0.012	119	0.012	0.018	NA	0.037	0.03
2a. Combustion Turbine Distillate Oil	0.6	0.212	0.03	0.116	0.0359	164	0.0016	0.0211	NA	NA	0.03
. Combustion Turbine Distillate Oil w/SWI	0.2	0.212	0.03	0.116	0.0359	164	0.0016	0.0211	NA	NA	0.03
a. Reciprocating Engine, Diesel	3.3500	0.0557	0.2393	0.7286	0.2293	162	NA	NA	NA	NA	NA
b. Reciprocating Engine, Diesel w/SCR	0.5025	0.0557	0.2393	0.7286	0.2293	162	NA	NA	NA	0.039	NA
. Pump-storage Hydroelectric	Check source note.										0
a. Purchases	Check source note.										

Electric Facilities Emissions Factors and Water Use

New Utility Facilities

	Heat Rate	Emissions (lbs/MWhr out) NOx	SOx	TSP	CO	VOC	CO2	CH4	N2O	H2S	NH3	Water Use (gals per MWhr out)
Baseload												
1a. Combined Cycle NG	8140	3.2	0.005	0.01	0.17	0.27	952	0.015	0.063	NA	NA	142
b. Combined Cycle NG w/SWI	8140	0.64	0.005	0.01	0.17	0.27	952	0.015	0.063	NA	NA	142
c. Combined Cycle NG w/SWI + SCR	8140	0.23	0.005	0.01	0.17	0.27	952	0.015	0.063	NA	0.3	142
2a. Combined Cycle Distillate Oil	8140	4	2.56	0.01	0.15	0.13	1330	0.013	0.265	NA	NA	142
b. Combined Cycle Distillate Oil w/SCR	8140	0.8	2.56	0.01	0.15	0.13	1330	0.013	0.265	NA	0.32	142
3a. Combined Cycle Residual Oil	8250	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4a. Coal, Pulverized w/scrubbers	9400	6	6	0.3	0.23	0.038	2240	0.014	0.306	NA	NA	455
5a. Coal, Atmospheric Fluidized Bed	10000	5	6	0.1	1.5	0.03	2380	0.015	0.325	NA	NA	15900
6a. Coal, Integrated Gasificaton Comb C	9280	1.9	3.1	0.03	0.09	0.03	1840	0.014	0.302	NA	NA	NA
7a. Geothermal, Flashed steam w/injectio	40000	NA	NA	NA	NA	NA	1.20	0.0004	NA	0.0664	NA	2224
8a. Solar, Thermal	14600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1007
b. NG, Boiler back-up unit	11000	1.65	0.007	0.032	0.42	0.014	1310	0.002	0.31	NA	NA	1023
c. NG, Boiler back-up unit w/LNB	11000	0.34	0.007	0.032	0.42	0.014	1310	0.002	0.31	NA	NA	1023
d. NG, Boiler back-up w/LNB + SCR	11000	0.13	0.007	0.032	0.42	0.014	1310	0.002	0.31	NA	NA	1023
9a. Solar, Photovoltaic	24000	0	0	0	0	0	0	0	0	0	0	0
10a. MSW, Steam Boiler	16800	5.17	6.4	7.896	16	0.504	2770	0.02	0.55	NA	NA	NA
b. MSW, Steam Boiler w/FFB	16800	5.17	6.4	0.079	16	0.504	2770	0.02	0.55	NA	NA	NA
11a. Wood, Steam Boiler	16740	2.59	0.14	8.139	3.7	1.29	3550	0.55	0.55	NA	NA	NA
b. Wood, Steam Boiler w/FFB	16740	2.59	0.14	0.08136	3.7	1.29	3550	0.55	0.55	NA	NA	NA
12a. Wind	7600	0	0	0	0	0	0	0	0	0	0	0
13a. Small Hydroelectric	3800	0	0	0	0	0	0	0	0	0	0	0
14a. Purchases		Check source note.										
Peakers												
1a. Combustion Turbine NG	13100	5.152	0.008	0.174	1.434	0.16	1560	0.16	0.24	NA	NA	0.4
b. Combustion Turbine NG w/SWI	13100	1.03	0.008	0.174	1.434	0.16	1560	0.16	0.24	NA	NA	0.4
c. Combustion Turbine NG w/SWI + SC	13100	0.371	0.008	0.174	1.434	0.16	1560	0.16	0.24	NA	NA	0.4
2a. Combustion Turbine Distillate Oil	13100	8	2.78	0.4	1.52	0.470	2150	0.021	0.276	NA	NA	0.4
b. Combustion Turbine Distillate Oil w/S	13100	3	2.78	0.4	1.52	0.470	2150	0.021	0.276	NA	NA	0.4
3a. Reciprocating Engine, Diesel	10000	33.500	0.557	2.393	7.286	2.293	1620	NA	NA	NA	NA	NA
b. Reciprocating Engine, Diesel w/SCR	10000	5.025	0.557	2.393	7.286	2.293	1620	NA	NA	NA	0.39	NA
4a. Pump-storage Hydroelectric	4900	Check source note.										
5a. Purchases		Check source note.										

Source Notes:

Bibliographic Key.

Tellus (a)	'Evaluation of Repowering the Manchester Street Station'. A report to the Rhode Island Division of Public Utilities and Carriers, Rhode Island Division of Statewide Planning, and Rhode Island Governor's Energy Office of Energy Assistance.
Tellus (b)	'The Role of Hydro-Quebec Power in a Least-Cost Resource Plan for Vermont'. A Report to the Vermont Department of Public Service, January 19, 1990.
ASF	'Atmospheric Stabilization Framework'. Model used to develop 'Policy Options for Stabilizing Global Climate: Draft Report to Congress', February 1989.
CEC (a)	California Energy Commision. 'Staff Recommendations for Generic Power Plant Emissions Factors (Final Version)', August, 1989.
CEC (b)	California Energy Commission, 'Energy Technology Status Report, July, 1990. Draft Copy.
ETH	'Energy Technology Characterization Handbook', DOE, March, 1983.
UNEP	United Nations Environment Program, 'The Environmental Impacts of Production and Use of Energy', January, 1985
Gleick	Peter H. Gleick et. al., 'Greenhouse-Gas Emissions from the Operation of Energy Facilities', July, 1989.
ADL	Arthur D. Little, Inc., 'Selective Catalytic NOx Reduction Technology for Cogeneration Plants', November, 1988
LUZ	Personal Communication with LUZ Development and Finance Corporation, 1990.
Goddard & Goddard	Goddard & Goddard, 'Global Warming and Geothermal Energy', Geothermal Resources Council Bulletin, January, 1990
Mintzer	Mintzer & Hedman, Externalities Associated with Electric Power Supply and Demand-Side Technologies.

New Utility Facilities

Baseload

1a. Combined Cycle NG. Sulfur content 0.0007%. Oxidation catalyst at 80% control for CO. Source: Tellus (a) for emissions (except NOx which is from CEC (a)) and chosen CO control level. Water consumption from CEC (b).

b. Combined Cycle NG w/SWI. Sulfur content is 0.0007%. Oxidation catalyst at 80% control for CO and SWI at 80% control for NOx. Source: Tellus (a) for emissions and chosen CO control level, CEC (a) for chosen NOx control level.Water consumption from CEC (b).

c. Combined Cycle NG w/SWI + SCR. Sulfur content is 0.0007%. Oxidation catalyst at 80% control for CO. SWI + SCR at 92.8% control for NOx which corresponds to 9 ppm . SWI reduces NOx emissions by 66.4% going from approximately 125 ppm to 42 ppm. This is followed by an additional 78.6 % reduction from SCR going from 42 ppm to 9 ppm. In the Northeast, this was considered the least cost combination of NOx control to achieve the NESCAUM regulation of 9 ppm. Source: Tellus (a) for emissions and chosen CO control level, CEC (a) for chosen NOx control level. NH# emissions are a Tellus calculation (see explanatory notes). Water consumption is from CEC (b).

2a. Combined Cycle Distillate Oil. Sulfur content is 0.3%, and ash is less than 0.1%. Oxidation catalyst at 80% control for CO. Source: Tellus (a) for emissions and chosen CO control level. Water consumption is assumed equivalent to CC NG

b. Combined Cycle Distillate Oil w/SCR. Sulfur content is 0.3%, and ash is less than 0.1%. Oxidation catalyst at 80% control for CO and SCR at 80% control for NOx. Source: Tellus (a) for emissions and chosen CO control level, CEC (a) for chosen NOx control level. The NH3 emissions are a Tellus calculation (see explanatory notes). Water consumption is assumed equivalent to CC NG.

3a. Combined Cycle Residual Oil. NA

4a. Coal, pulverized w/scrubbers. Sulfur content is 2.5% and ash content is 12%. Scrubbers at 83% control for SOx and 90% control for TSP. Source: Tellus (a) for emissions (except CO2 which comes from Gleick to reflect Western coal). Internal calculation to estimate control levels. Water consumption from ETH.

5a. Coal, Atmospheric Fluidized Bed Combustion. Sulfur content is 2.5% and ash content is 12%. Source: Tellus (a) (except coal which comes from Gleick to reflect Western coal). Water consumption from CEC (b).

6a. Coal, Integrated Gasification Combined-Cycle. Sulfur content is 1.4% and ash content is 6.25%. Source: Tellus (a) (except CO2 which comes from Gleick to reflect Western coal).

7a. Geothermal, Flashed steam w/injection. Average of the 9 CECI Coso plants, 8 under construction. Air Emissions Control Systems (AECS) utilizing noncondensible gas injection. Heat Rate is assumed 40000 Btu/KWhr. Source: Goddard & Goddard for emissions, Tellus for Heat Rate.

Water consumption from LUZ.

8a. Solar, Thermal. The cycle consists of tracking heliostats which are automatically steered to reflect direct solar radiation onto the receiver. The energy is transferred to a working fluid which is a heat source for the thermodynamic cycle. Source: UNEP. This cycle generates electricity. Water consumption from LUZ.

b. NG Boiler back-up unit. Sulfur content is .0007%. Source: CEC (a) for SOx, TSP, CO, CO2 and VOC emissions, ASF for CH4 and N2O emissions. Emissions for a solar thermal facility with NG boiler back-up will be a weighted (by % of generation) average of these two facilities. Water consumption from LUZ.

c. NG Boiler back-up unit w/LNB. Sulfur content is .0007%. Source: CEC (a) for SOx, TSP, CO, CO2 VOC emissions, LUZ for NOx emissions, ASF for CH4 and N2O emissions. The NOx value reflects emissions at the LUZ SEGS VIII and IX projects. Emissions for a solar thermal facility with NG boiler back-up will will be a weighted (by % of generation) average of these two facilities. Water consumption from LUZ.

d. NG Boiler back-up unit w/LNB + SCR. Sulfur content is .0007%. Source: CEC (a) for SOx, TSP, CO, CO2 VOC emissions, LUZ for NOx emissions, ASF for CH4 and N2O emissions. The NOx value reflects emissions at the LUZ SEGS VII and IX projects. Emissions for a solar thermal facility with NG boiler back-up will be a weighted average (by % of emissions) of these two facilities. Water consumption from LUZ.

9a. Solar, Photovoltaic. Source: UNEP. The plant consists of single-crystal silicon photovoltaic cell which convert the solar radiation directly into electricity.

10a. MSW, Steam boiler. Sulfur content is 0.17%. Source: CEC (a) for NOx, SOx, TSP, CO, VOC, and CO2 emissions. Source: ASF for CH4 and N2O emissions.

b. MSW, Steam Boiler. Sulfur content is 0.17%. FFB at 99% control for TSP. Source: CEC (a) for NOx, SOx, TSP, CO, VOC, CO2 emissions, and chosen TSP control level. ASF for CH4 and N2O emissions.

11a. Wood, Steam Boiler. Using Douglas fir wood waste. Source: CEC (a) for NOx, SOx, TSP, CO, VOC, and CO2 emissions. Source: ASF for CH4 and N2O emissions.

b. Wood, Steam Boiler. Using Douglas fir wood waste. FFB at 99% control for TSP. Source: CEC (a) for NOx, SOx, TSP, CO, VOC, CO2 emissions, and chosen TSP control level, ASF for CH4 and N2O emissions.

12a. Wind. This represents a central wind farm. Source: ETH.

13a. Small Hydroelectric. A plant with less than 15 MW of capacity and usually fed by a dam with height no more than 65 ft. Impounding is less than 500 acres. Source: UNEP.

14a. Purchases. Emission coefficients from purchases should reflect the appropriate fuel mix and emission coefficients from utility system from which purchases originate.

Peakers

1a. Combustion Turbine NG. Sulfur content is 0.0007%. Source: CEC for NOx, SOx, TSP, CO, VOC, and CO2 emissions, ASF for CH4 and N2O emissions. Water consumption from CEC (b).

b. Combustion Turbine NG. Sulfur content is 0.0007%. SWI at 80% control for NOx. Source: CEC for NOx, SOx, TSP, CO, VOC, CO2 emissions and chosen NOx control level. ASF for CH4 and N2O emissions. Water consumption from CEC (b).

c. Combustion Turbine NG w/SWI + SCR. Sulfur content is 0.0007%. SWI + SCR at 92.8% control for NOx which corresponds to 9 ppm . SWI reduces NOx emissions by 66.4% going from approximately 125 ppm to 42 ppm. This is followed by an additional 78.6 % reduction from SCR going from 42 ppm to 9 ppm. In the Northeast, this was considered the least cost combination of NOx control to achieve the NESCAUM regulation of 9 ppm. Source: Tellus (a) for emissions and chosen CO control level, CEC (a) for chosen NOx control level. NH# emissions are a Tellus calculation (see explanatory notes). Water consumption is from CEC (b).

2a. Combustion Turbine Distillate Oil. Sulfur content is 0.2%. Source: Tellus (b). Water consumption assumed equivalent to NG CT.

b. Combustion Turbine Distillate Oil w/SWI. Sulfur content is 0.2%. SWI at 70% control for NOx. Source: Tellus (b) for uncontrolled emissions, CEC (a) for chosen NOx control level. Water consumption assumed equivalent to NG CT.

3a. Reciprocating Engine, Diesel. Sulfur content is .25%, HR is a Tellus estimate. Source: CEC (a).

b. Reciprocating Engine, Diesel w/SCR. Sulfur content is .25%, HR is a Tellus estimate. SCR at 85% control for NOx. Source: CEC (a) for emissions and chosen control level. The NH3 emissions are a Tellus calculation. See explanatory notes.

4a. Pump-storage Hydroelectric. A typical plant may consist of four 250 MW pumps and drivers that utilize base load power during off-peak demand for pumping water from a lower to a higher reservoir. The pumping units become turbines driving electrical generators when the stored water is during periods of high demand. Source: UNEP. Emissions from pump storage hydroelectric arise from the pumping stage and not the released electricity generation stage. The emissions will therefore depend on the mix of pumping devices.

5a. Purchases. Emission coefficients from purchases should reflect fuel mix and emission coefficients from utility system from which purchases originate.

Explanatory Notes and Adjustment Specifications:

Control Devices.

Control levels can be adjusted on the facilities with control devices in place (affecting only the level of the controlled pollutant). The adjustment can be performed as follows:

$$E1 = E0 * (1-Y)/(1-X)$$

where E1 is the pollutant emission rate after desired control adjustment, E0 is the pollutant emission rate before adjustment, X is the original control level (in decimal from), Y is the desired control level (in decimal form). Refer to the explanatory notes for a reasonable range of control level. This adjustment should be made on both emissions per energy in and energy out.

Heat Rates.

The above emission coefficients per unit energy out can be adjusted if a different heat rate is desired. The adjustment can be performed as follows:

$$E1\ out = E0\ out * (HR1/HR0)$$

where E1 out is the pollutant emission rate after desired heat rate adjustment, E0 out is the pollutant emission rate before adjustment, HR1 is the adjusted heat rate, HR0 is the original heat rate.

Fuel Sulfur Content.

SOx emissions can be adjusted by changing the amount of sulfur present in the fuel. This adjustment can be made as follows:

$$SOx1 = SOx0 * (S1/S0)$$

where SOx1 is the adjusted SOx emission rate, SOx0 is the original SOx emission rate, S1 is the adjusted fuel sulfur percentage (in decimal form), and So is the original fuel sulfur percentage (in decimal form).

NH3 Emissions

Ammonia emissions are given in ADL, 1989 for existing energy producing facilities with SCR devices enabled. These emission rates ranged from .0157 lbs/MMBtu to .0777 lbs/MMBtu. An average of these emission rates, .0391 lbs/MMBtu corresponds to an average control level of 83%. This NH3 emission level was linearly adjusted in the tables to reflect the SCR control level. These values are considered approximate.

On-System Offsets

1. COGENERATION: Electricity producing facilities that produce usable steam in addition to their output of electricity can displace emissions from steam producing devices. The expression for the net emission rate for a cogenerator can be expressed as follows:

$$En = Eg - Eb*(Sc/Sb)$$

   where En is the net cogenerator emission rate, Eg the gross cogenerator emission rate, Eb the gross avoided boiler emission rate, Sb the steam efficiency of the displaced boiler (out/in), and Sc the steam efficiency of the cogenerating facility (=[1-3414/HR]*F, where HR is tre electric heat rate and F is the fraction of waste heat captured for thermal uses). We recommend that the power developer quantify the offsets (i.e. Eb*(Sc/Sb)).
2. LANDFILL DECOMPOSITION OFFSETS: The use of municipal solid waste and wood waste in electricity generating facilities can displace emissions from decomposition in landfills. Average emissions from municipal solid waste landfills are 5 lbs/MMBtu and 12 lbs/MMBtu for CH4 and CO2, respetively. We recommend that the power developer quantify these offsets.
3. SUSTAINABLE WOOD YIELD OFFSETS: Live biomass respiration can displace some of the emissions of wood burning facilities. We recommend that the power developer quantify the offsets.

ieothermal Emissions

The geothermal emissions presented here are not considered wholly representative of potential geothermal emissions in Nevada. Geothermal emissions are very site-specific and emission values should be submitted by potential developers if anticipated emissions are substantially different from those presented here.

v Utility Facilities

aseload

a. Combined Cycle NG. The potential range for the CO control using oxidation catalyst is 80 - 90%. Source: CEC (a) for control range.
b. Combined Cycle NG w/SCR. The potential range for CO control using oxidation catalyst is 80 - 90%. The potential range for NOx control using SCR is 80 - 90%. Source: CEC (a) for control ranges.
ι. Combined Cycle Distillate Oil. The potential range for CO control using oxidation catalyst is 80 - 90%. Source: CEC (a) for control range.
). Combined Cycle Distillate Oil w/SCR. The potential range for CO control using oxidation catalyst is 80 - 90%. The potential range for NOx control using SCR is 80 - 90%. Source: CEC (a) for control ranges.
a. Combined Cycle Residual Oil.
ι. Coal, pulverized w/scrubbers.
a. Coal, Atmospheric Fluidized Bed Combustion.
ι. Coal, Integrated Gasification Combined-Cycle.
ι. Geothermal, Flashed steam w/injection.
a. Solar, Thermal.
). NG Boiler back-up unit.
.. NG Boiler back-up unit w/LNB.
i. NG Boiler back-up unit w/SCR.
ι. Solar, Photovoltaic.
'a. MSW, Steam boiler.
b. MSW, Steam Boiler w/FFB.
a. Wood, Steam Boiler.
b. Wood, Steam Boiler w/FFB.
a. Wind.
a. Small Hydroelectric.
a. Purchases.

akers

. Combustion Turbine NG.
. Combustion Turbine NG. The potential range for NOx control using SWI is 70 - 82%. Source: CEC for control range.
. Combustion Turbine Distillate Oil.
). Combustion Turbine Distillate Oil w/SWI. The potential range for NOx control using SWI is 70 - 82%. Source: CEC for control range.
. Reciprocating Engine, Diesel.
). Reciprocating Engine, Diesel w/SCR. The potential range for NOx control using SCR is 80 - 90%. Source: CEC for control range.
.. Pump-storage Hydroelectric.
. Purchases

TABLE 2

VALUATION OF ENVIRONMENTAL COSTS

Pollutant	Valuation (1990 dollars/lb)
Carbon Dioxide (CO_2)	0.011 1.1
Methane (CH_4)	0.11
Nitrous Oxide (N_2O)	2.07
Nitrogen Oxides (NO_2)	3.4[1] 0
Sulfur Oxides (SO_x)	0.78
Volatile Organic Compounds (VOC)	0.59[2]
Carbon Monoxide (CO)	
Ambient Air Quality +	0.43[1]
Global Warming Contribution	0.03
Total	0.46
Total Suspended Particulates/ Particulate Matter (Diam<10MM) TSP/PM_{10}	2.09[1]
Hydrogen Sulfide (H_2S)	NA[3] use proxy
NH_1	0
Water Impact	Site Specific (Determined by Utility)
Land Use	Site Specific (Determined by Utility)

[1]The value is applicable to EPA attainment areas. The value for an EPA non-attainment area is equal to or greater than the amount and is likely to be site specific.

[2]The value for VOC has been adjusted to reflect the state of Nevada's status as attainment for VOC. This value is representative of an actual cost incured in Nevada to control fugitive VOC ammissions from gasoline. The value for an EPA non-attainment area is $2.75/lb.

[3]A national marginal control cost for H_2S in attainment areas would be approximately $0.9 per lb. (OTA, 1989). The valuation of H_2S in progress at this time.

FINAL RULE FOR DOCKET NO. 89-752

AS ADOPTED BY THE PUBLIC SERVICE COMMISSION OF NEVADA

JANUARY 22, 1991

Section 1. NAC 704.9365 is hereby amended to read as follows:

A utility's plan for supply must develop and document the origins of:

1. Its assumptions, data and projections used to calculate the costs and benefits of its options.

2. The costs, benefits and feasibility of power transactions with other utilities including nonfirm and firm energy and the costs of transmission;

3. Its basic economic limitations and availability of fuels;

4. Required controls to mitigate pollution at planned facilities when estimating the costs of the facilities for the plan;

5. Criteria selected for determining the reserve margin;

6. Assumptions for conventional generation;

7. Assumptions for renewable resources;

8. Assumptions for nonutility generators;

9. Estimates of the cost of, the requirements of time for and the feasibility of converting to the use of coal;

10. A statement of the limits on its import or export of power within its primary system of generation and transmission;

11. A statement of the utility's requirements for research and development;

12. A statement of potential projects for upgrading existing systems for transmission of new interties;

13. The criteria used by the utility in setting the dates for the retirement of its facilities; and

14. A statement quantifying the environmental costs and the net economic benefits added to the state from each option for future supply.

Section 2. NAC 704.937 is hereby amended to read as follows:

NAC 704.937 List of [options] alternative plans for future supply of electricity; criteria for selection.

1. A utility's plan must include a list of all existing and planned facilities for conventional generation, facilities for using renewable resources, nonutility generators, programs for reducing demand for and use of energy and other sources available as options to the utility for the future supply of electricity. The listing must include the capacity and projected loads of the facilities and resources for each year of the plan.

2. A utility shall identify the criteria it has used for the selection of its options for meeting the expected future demands for electricity and shall explain how any conflicts among criteria are resolved.

3. In comparing [its options,] alternate plans containing different resource options, the basic criterion which the utility shall use to select and rank [its options] the alternate plans for the supply of power is the present worth of future requirements for revenue (PWRR). [If an option selected by the utility as its preferred option fails to produce the lowest present worth of revenue requirements, the utility must fully justify its choice by setting forth the other criteria which influenced the utility's choice.] A comparison of the PWRR for each alternate plan shall be presented in each resource plan.

4. Another important criterion which the utility shall use to select and rank its options for the supply of power is the present worth of societal costs (PWSC). The present worth of societal costs of a particular plan is obtained by adding the environmental costs to the PWRR.

[4.]5. Other criteria which the utility shall consider are the avoidance of risk by means of:

(a) Flexibility;

(b) Diversity;

(c) Reduced size of commitments;

(d) Choice of projects which can be completed in short periods; [and]

(e) Reliability; and

[(e)](f) Displacement of fuel.

[5.]6. The utility's selections must:

(a) Provide adequate reliability;

(b) Be within regulatory and financial constraints; and

(c) Meet the requirements for environmental protection.

7. If a plan selected by the utility as its preferred plan fails to produce the lowest present worth of future revenue requirements (PWRR) or the lowest present worth of societal costs (PWSC), the utility must fully justify its choice by setting forth the other criteria which influenced the utility's choice. As more fully described in Section 5, the selection of a plan by the utility must in certain cases include an analysis of the net economic benefits to the State of Nevada for that plan.

Section 3. NAC 704.939 is hereby amended to read as follows:

1. A utility's plan must contain a list showing:

(a) All sources of electric power from which the utility has plans or potential opportunities to buy electric power during the 20 years covered by the plan; and

(b) The amount of electric power to be purchased from each source and the years for which delivery is contracted.

The nature and source of the purchase must be described (e.g. nonfirm electric power in winter months [only] from a combustion turbine fueled by natural gas). The net environmental costs and the net economic benefits added to the state from each source or mix of resources must be quantified. If a purchase is not from a specific source of supply then the environmental costs and any economic benefits added from the mix of resources of the seller must be described. Major new commitments for purchases of power must be documented and justified as economical options for supply of power.

Section 4. NAC 704.9395 is hereby amended to read as follows:

1. The estimated costs of construction, including:

(a) Annual flows of expenditures, in current dollars, with allowance for funds used during construction; and

(b) Annual flows of expenditures, in current dollars, without allowance for funds used during construction;

2. The estimated costs of operation, including:

(a) Costs which are variable, in current dollars, per kilowatt-hour, with expenses for fuel and other items indicated separately; and

(b) Costs which are fixed in current dollars, per kilowatt-hour;

3. Net environmental costs and net economic benefits to the state which are more fully described in Sections 5 and 7.

[3.]4. The rates of escalation of cost, including:

(a) Capital costs;

(b) Costs which are variable and related to fuel;

(c) Operating costs which are variable and unrelated to fuel; [and]

(d) Operating costs which are fixed; and

(e) Environmental costs.

[4.]5. The annual average cost per kilowatt-hour at projected loads in current dollars for each year of the plan for each facility, both existing and planned.

Section 5. Economic Benefits Analysis

1. An analysis of the changes which result in net economic benefits added to the State of Nevada from electricity producing or electricity saving resources shall be conducted by the utility in selecting a resource option. The net economic benefit added to the state must be quantified to reflect both the positive and negative changes. The projected present worth of societal costs (PWSC) of a competing resource plan must be within ten (10) percent of the lowest societal cost plan before proceeding with an analysis of the economic benefits to the State of Nevada.

2. The economic benefits analysis shall be achieved by calculating the portion of the present worth of future requirements for revenue (PWRR) that is expended within the State of Nevada including the following for both the construction and operation phases of any project:

(a) Capital expenditures for land and facilities located within the state or equipment manufactured in the state;

(b) The portion of the cost of materials, supplies, and fuel purchased in the state;

(c) Wages paid for work done within the state;

(d) Taxes and fees paid to the state or subdivisions thereof; and

(e) Fees paid for services performed within the state.

3. The analysis shall consider only the net benefit added to the economy of the state of that portion of expenditures made within the State.

4. The PWSC's of the competing resources shall then be adjusted by the Commission to consider either all, or only a portion, of the calculated economic benefit.

Section 6. NAC 704.9475 is hereby amended to read as follows:

1. A utility shall conduct an analysis of sensitivity for all major assumptions and estimates used in its plan. The analysis must include the:

(a) Forecast of load;

(b) Dates when proposed acquisitions will be in service;

(c) Unit availability;

(d) Costs of power plants;

(e) Price of fuel;

(f) Amount of purchased power and corresponding costs;

(g) The schedule, impact and costs of programs of conservation and load management;

(h) Capacity of plans in megawatts;

(i) Discount rates;

(j) Rate of inflation; [and]

(k) Cost of capital;

(l) Environmental costs; and

(m) Economic benefit.

2. The utility shall state the ranges and consequences of uncertainty for each of the assumptions and methods of combining various uncertainties.

Section 7. Environmental cost quantification.

1. The environmental costs to the state associated with operating and maintaining a plan for supply or demand must be quantified for air emissions, water and land use. Environmental costs are those costs, wherever they may occur, which result from harm or risks of harm to the environment after the

application of all mitigation measures required by existing environmental regulation or otherwise included in the plan.

2. The utility must use the general emission rates and the environmental damage costs established by the Commission unless the utility justifies deviating from these values.

Section 8.

The environmental factors identified as a result of this rule and the emission rates and environmental costs set by the Commission may be subject to elimination or modification, and new factors may be added for consideration, as new scientific, engineering, economic, or other technical information becomes available to the commission. Information purporting to establish a need for the deletion or addition of any environmental factor or the revision of any emission rates or environmental costs may be presented by any party at the time of a hearing on the utility's resource plan.

SECTION 9.

"Environmental costs and economic benefits to the state" defined. "Environmental costs and economic benefits to the state" means costs and benefits inuring to the state from electricity produced for consumption within the state whether the generation source is located within or outside Nevada. To calculate environmental costs of generation from sources outside the state, the cost should be calculated the same as if the electricity were generated in the State of Nevada.

PV Central Receivers: Their Potential Role in Solar-Electric Generation

R. M. Swanson
SunPower Corporation

At present, photovoltaic modules provide power for a growing number of remote power applications. They cannot compete with large, central-station fossil fueled generators. Installed prices in the $1 to $2 per watt range are required to serve this vast market. It is possible that the price of conventional, flat-plate photovoltaic systems will eventually drop into this range; however, a number of analyses, both manufacturing cost studies and learning curve projections, cast doubt on whether this can happen prior to the year 2020.

A possible approach to lower cost photovoltaic systems has been through light concentration. This allows the use of a concentrating collector, which presumably has a lower cost per unit area than photovoltaic modules, in combination with a photovoltaic converter which operates at high power density. The high power density at the converter permits the use of highly-engineered, highly-efficient photovoltaic devices. The attractiveness of this approach has been considerably enhanced by the development of silicon concentrator cells with efficiencies over 28 percent. These devices appear to be manufacturable for less than $0.30 per watt.

The remaining impediment to photovoltaic concentrator systems is development of a suitable concentrator. Many approaches have been tried but the approach currently favored by most is based on Fresnel lenses. These have many attractive features; however, SunPower believes that they are not capable attaining the central-station cost goal. After studying many alternatives, SunPower has concluded that central-receiver concentrators based on heliostats offer the lowest cost potential. This paper will discuss SunPower's approach and findings.

The attractiveness of central receiver photovoltaic systems stems from a combination of factors. First, heliostats have had considerable development under the Federal solar-thermal program. They constitute the lowest cost means of concentration. Second, SunPower has developed a photovoltaic dense-array receiver capable of operating at 30 watts per square centimeter. By centralizing the electric generation in a high-power central-receiver the costs associated with having generation distributed over a large field are reduced. Finally, the high-efficiency of recently-developed silicon solar cells begin to approach that of conventional heat engines, but without their complexity and operating costs. SunPower intends to market photovoltaic central-receiver power plants at under $2.00 per watt by 1995.

PV Central Receivers

Their Potential Role in Solar-Electric Generation

R. M. Swanson
SunPower Corporation

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Conventional Paradigm for the Emergence of Large-Scale Photovoltaic Power Generation

(The Intermediate Market View)

- Increasing production volume lowers module price
- Lower module price opens new and larger markets
- This supports further increase in production and reduction in module price
- This cycle repeats until large-scale photovoltaic power generation is economical

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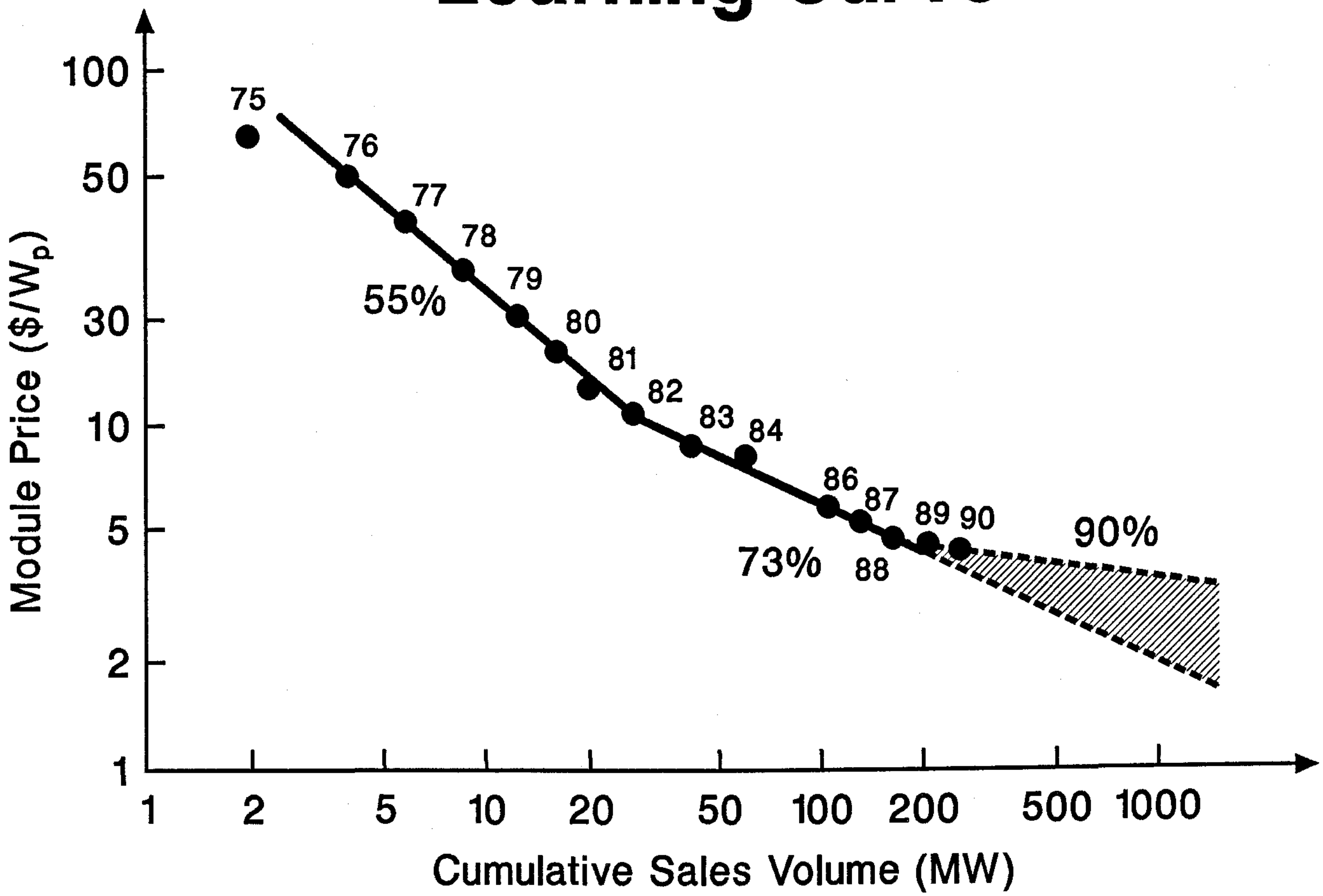
Flat-Plate Module Price Learning Curve



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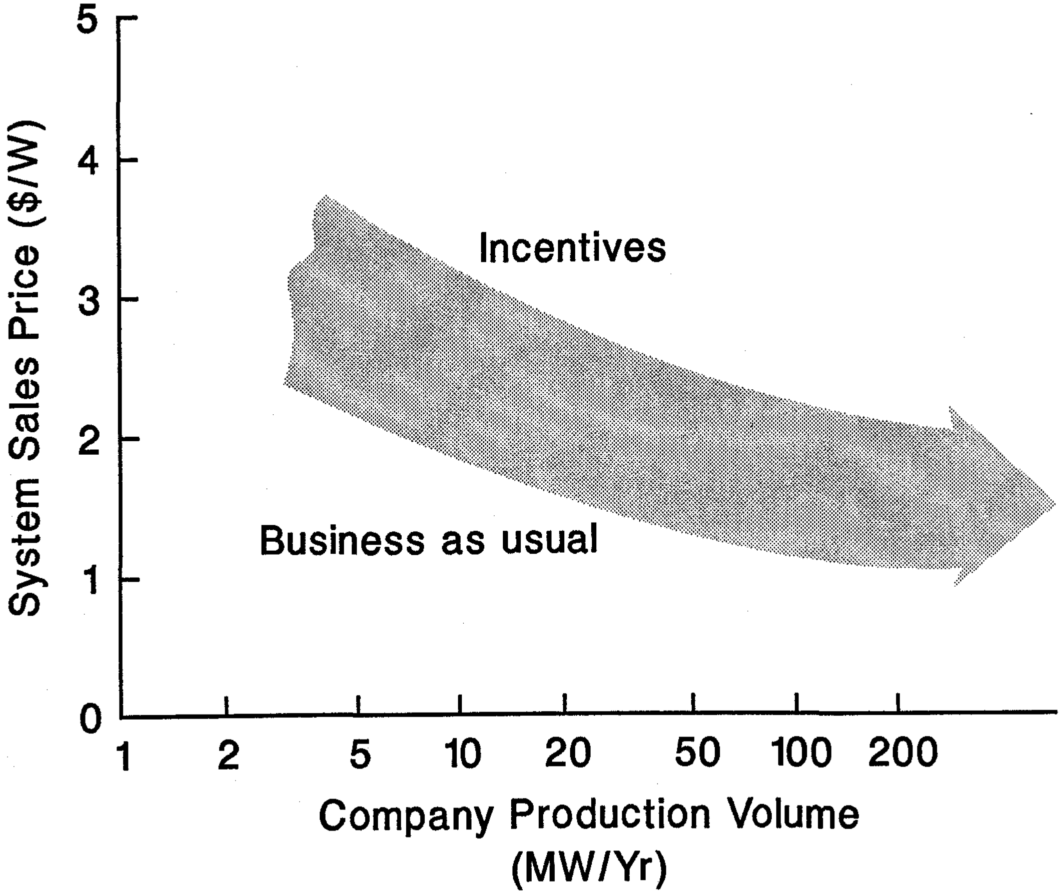
Central Station Photovoltaic Market



* Assumes 20% market share

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Root Cause of High Cost

- Sunlight is diffuse, requiring large areas
- Converting sunlight to electricity is difficult

Therefore

308 A large-area, solid-state solar energy converter is expensive due to:

- Large usage of expensive electronic materials
- Large number of parts
- Stringent requirements on production uniformity and yield

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Solution

Concentrate the sunlight on a highly efficient, high power density energy converter using

- Fresnel lenses
- Reflective troughs
- Reflective dishes
- Central receivers

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SunPower's View

- Central-station markets will be served by different products than remote markets
- Concentrating photovoltaic systems are not suitable for remote applications
- Only technologies capable of installed prices below $2 per watt are candidates for central-station applications
- Flat-plate systems are unlikely to reach this price -- it might be feasible with some concentrating approaches

SunPower

Product Requirements

Remote Applications

- Less costly than alternative sources of energy
- High reliability
- Unattended operation
- Ease of installation with simple equipment
- Ease of maintenance

Central-Station Applications

- Low capital cost
- Low operation and maintenance cost

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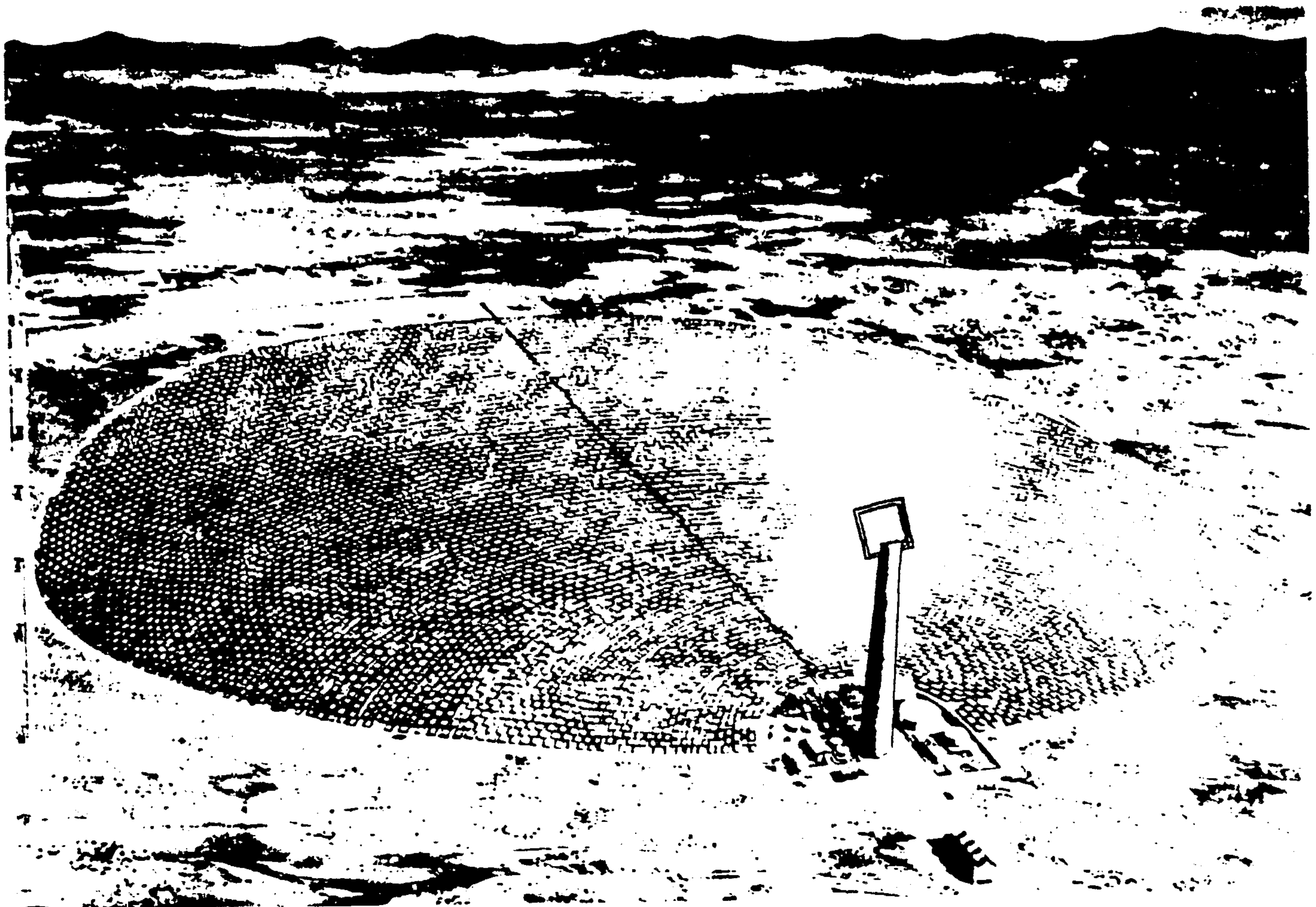
Photovoltaic Central Receiver Concept



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Why Central Receiver Photovoltaic Systems Are Attractive

313

- Heliostats are lowest-cost means of concentration
- High-efficiency, high-concentration silicon solar cells provide cost-effective conversion
- Cost-effective dense array package

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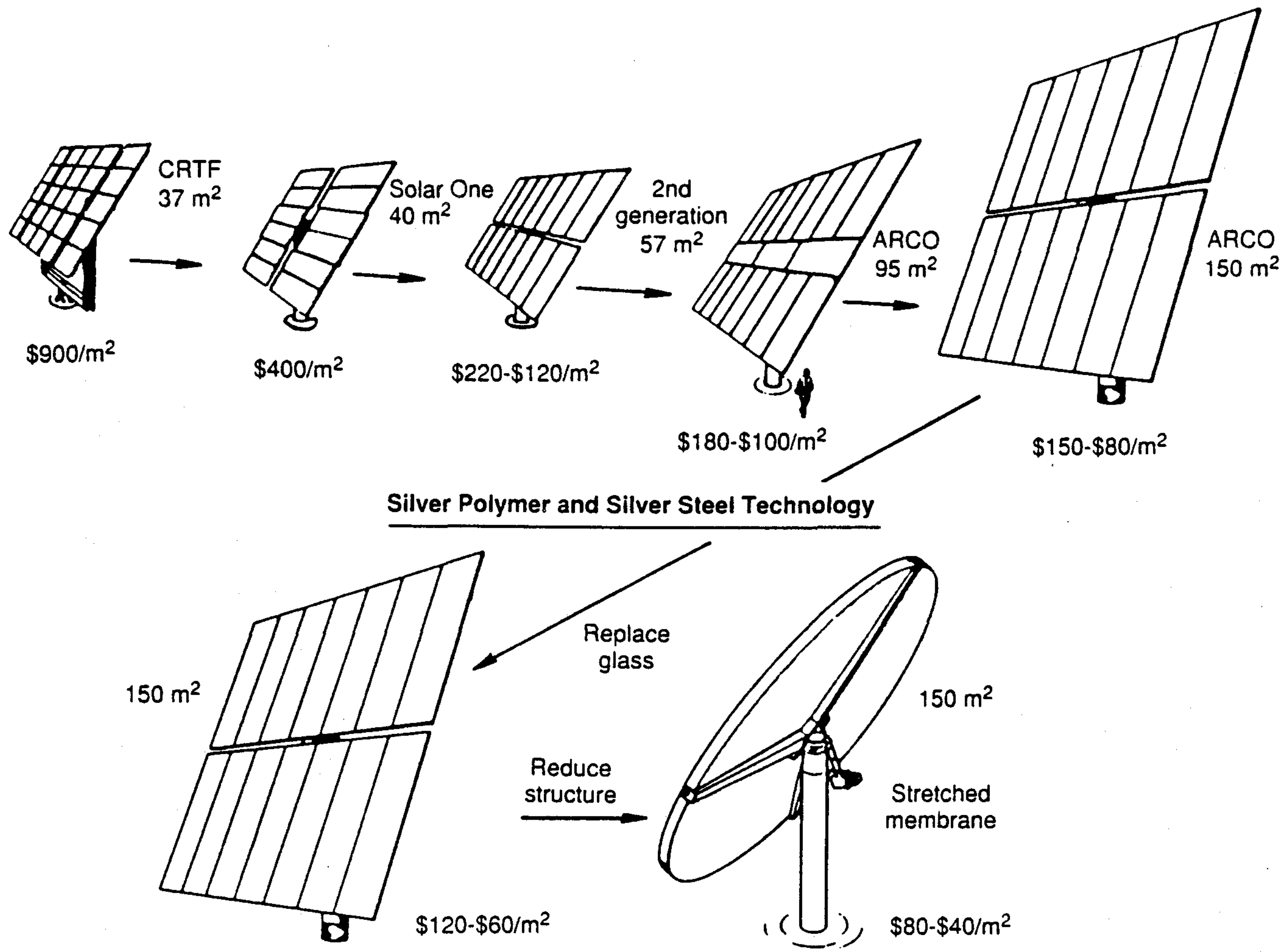
DOE Heliostat Development Progress



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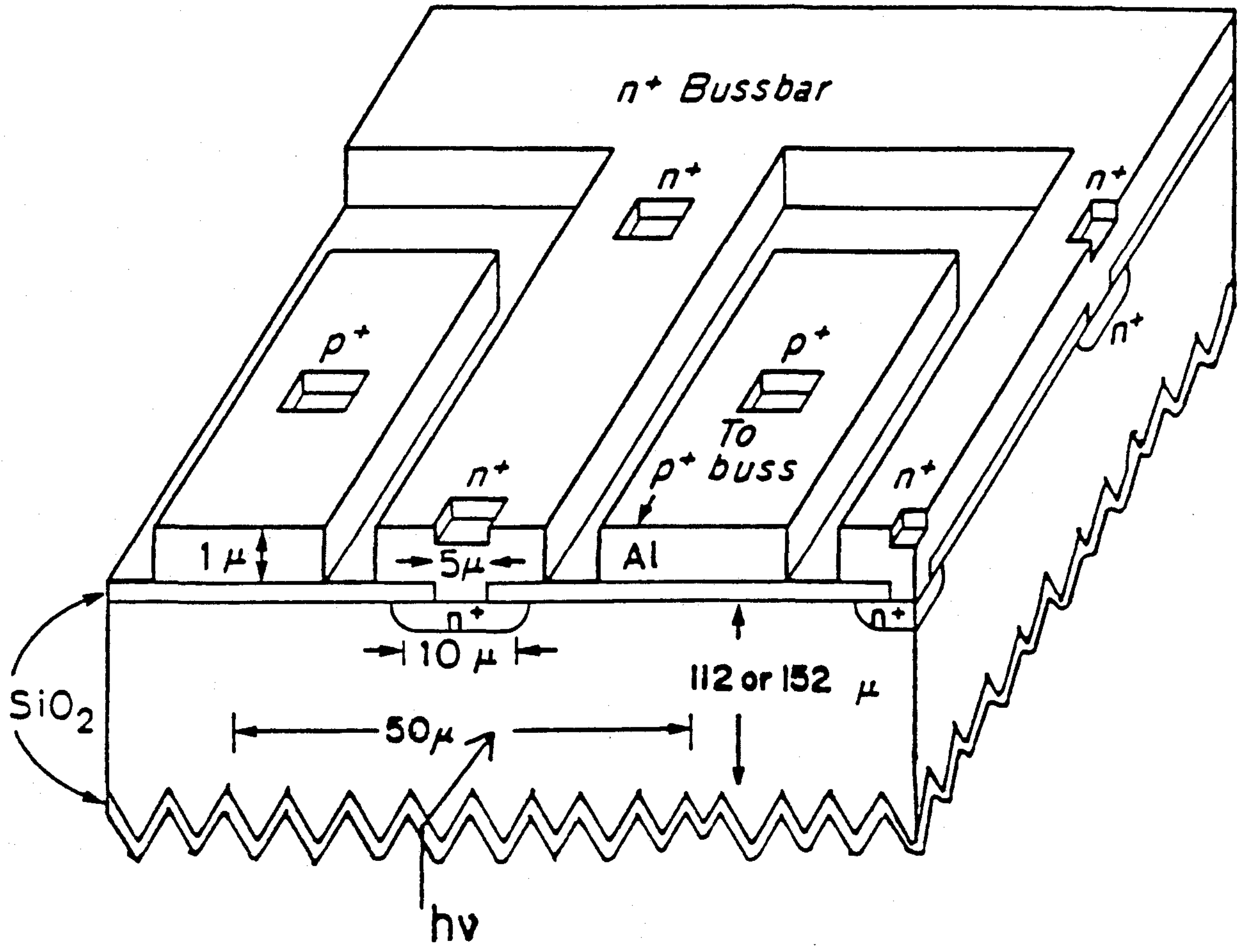
PCPV Cell



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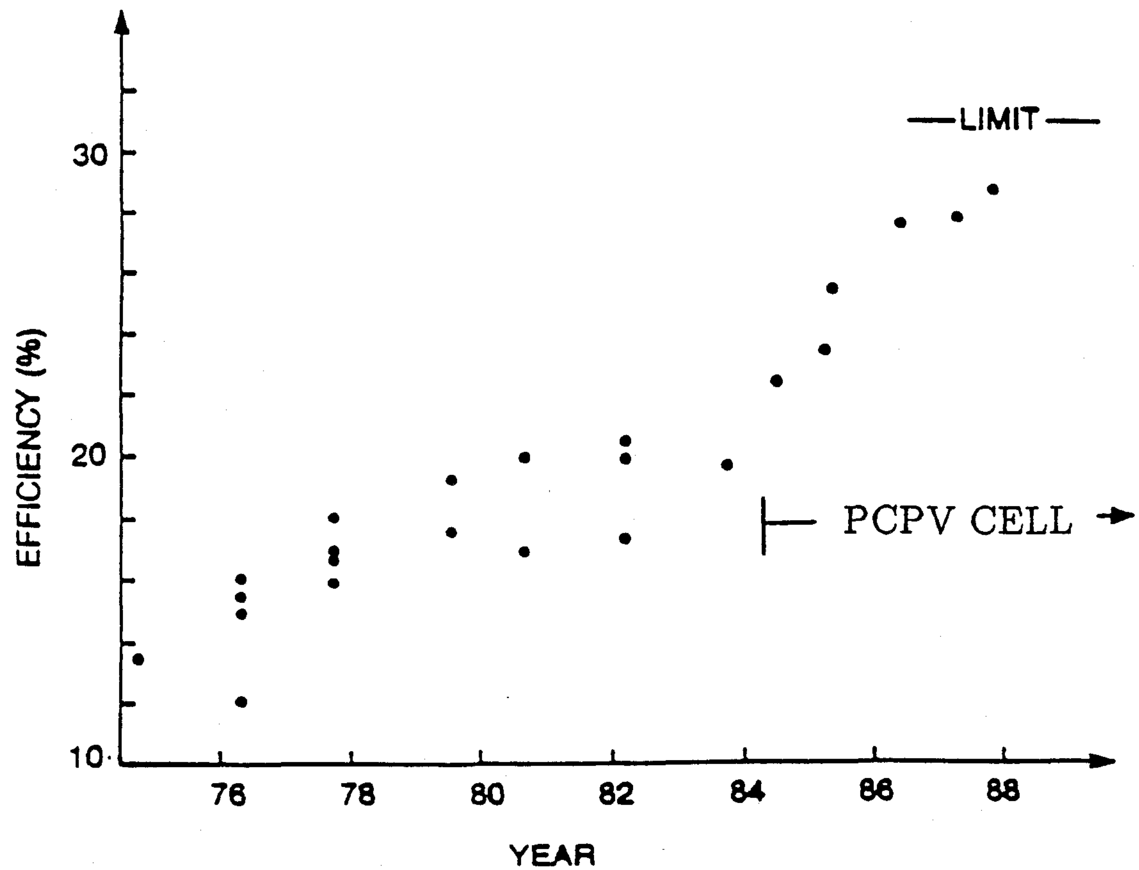
Silicon Concentrator Cell Efficiency Versus Year



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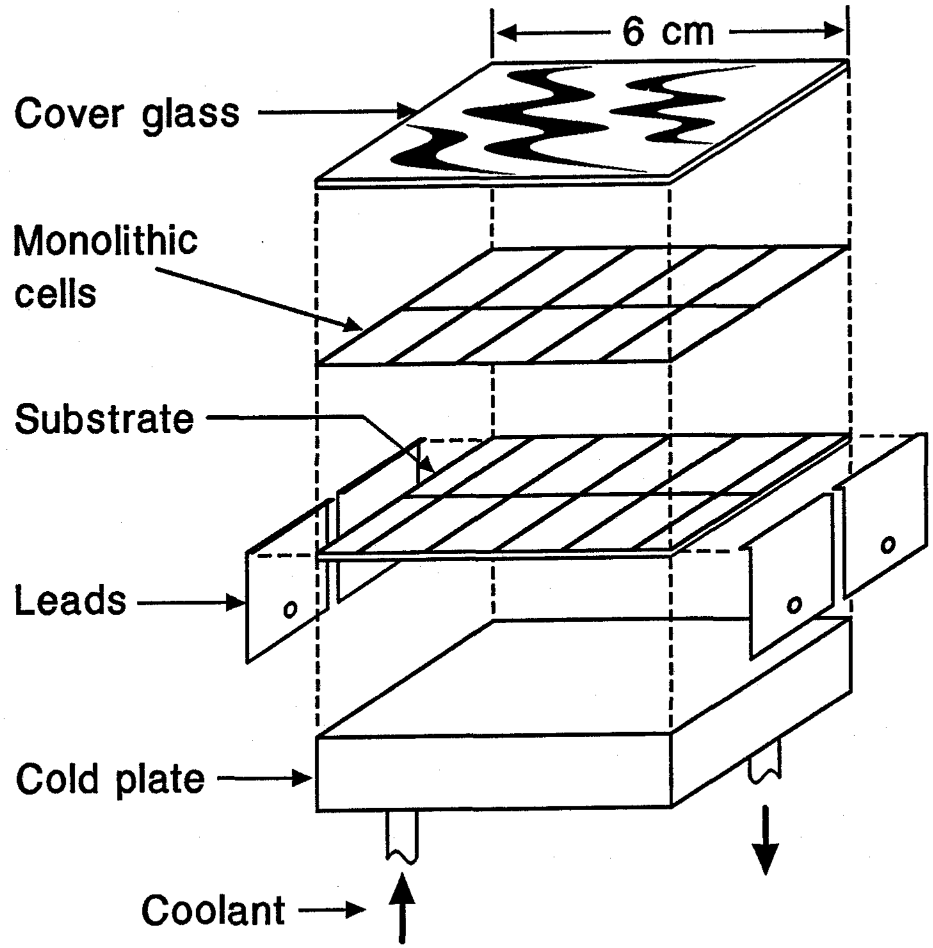
SunPower 200 Watt Submodule

Exploded View



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Major Technical Issues

- Cells must be actively cooled to maintain temperatures below 70°C with 30 watts per square centimeter incident flux
- Cell interconnection schemes must deal with very non-uniform intensity over receiver
- A dense-array package must have many closely spaced cells with minimal inactive area and yet have low electrical resistance

However

- Large federal development effort on low-cost heliostats can be utilized
- Testing program can utilize the CRTF at Sandia National Laboratories

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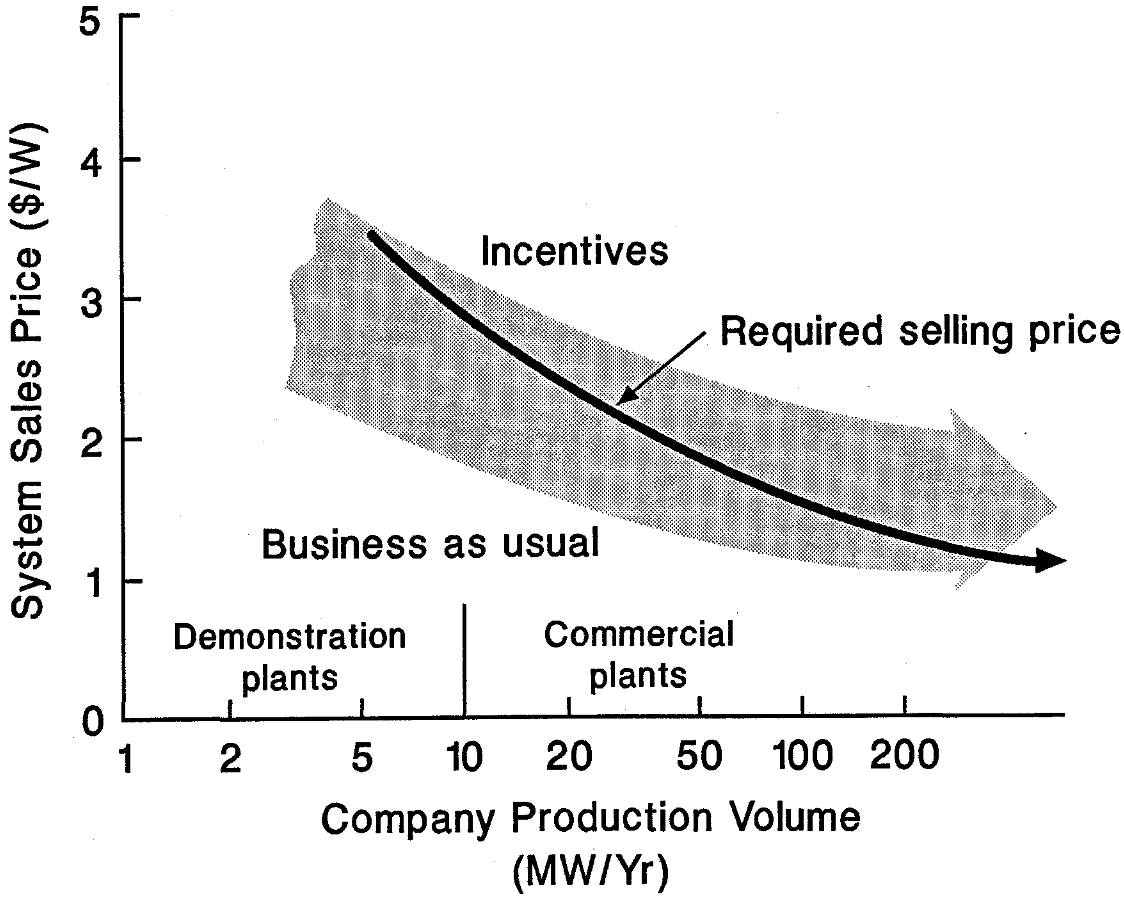
Central Station Photovoltaic Market



* Assumes 20% market share

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Comparison with Solar Thermal Plants

Advantages

- Potentially higher efficiency (except for the largest, most advanced solar thermal plants)
- Higher capacity factor due to no dynamic losses
- Lower operation and maintenance cost
- Smaller sizes are possible
- Reduced development cost and risk

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Comparison with Solar Thermal Plants

Disadvantages

- No hybrid fuel capability
- Lack of cost-effective storage

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Conclusion

Central receiver systems are an attractive addition to the U. S. photovoltaic technology mix

Look for cost-effective, central-station plants by 1995

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