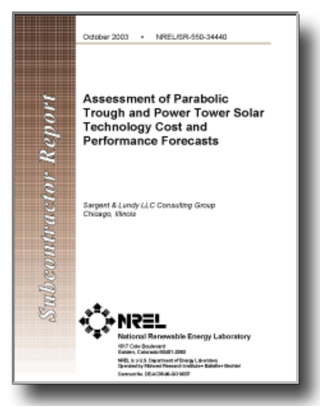
October 2003 • NREL/SR-550-35060

Subcontractor Report

Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts

Sargent & Lundy LLC Consulting Group
Chicago, Illinois


October 2003 • NREL/SR-550-34440

Subcontractor Report

Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts

Sargent & Lundy LLC Consulting Group
Chicago, Illinois

National Renewable Energy Laboratory

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

October 2003 • NREL/SR-550-35060

Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts

Sargent & Lundy LLC Consulting Group
Chicago, Illinois

NREL Technical Monitor: H. Price

Prepared under Subcontract No. LAA-2-32458-01

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

NOTICE

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

ASSESSMENT OF
PARABOLIC TROUGH AND POWER TOWER SOLAR TECHNOLOGY
COST AND PERFORMANCE FORECASTS

SUMMARY OF CONTENTS OF FULL REPORT

Section | Page

CONTENTS (CONT.)

APPENDIXES TO FULL REPORT

A. List of Documents

B. Methodology

C. Levelized Cost for Ranking Alternatives and Example Calculations

D. Evaluation Of Technology Improvements And Capital Cost Projections For Parabolic Trough Solar Plants

E. Evaluation of Technology Improvements and Capital Cost Projections – Tower

F. Evaluation of O&M Costs — Trough

G. Evaluation of O&M Costs — Tower

H. Mirror Reflectivity (SunLab Input)

I. Sargent & Lundy Response to the NRC Issues and Observations

ACRONYMS AND ABBREVIATIONS

Term	Definition or Clarification
°C / °F	Degrees Celsius/degrees Fahrenheit
ADL	AD Little
ATS	Advanced Thermal Systems
CHP	Combined heat and power
CRADA	Cooperative Research and Development Agreement
CSP	Concentrating Solar Power
DOE	Department of Energy
DSCR	Debt service coverage ratio
DSG	Direct steam generation
EERE	Office of Energy Efficiency and Renewable Energy (a part of the DOE)
EPSG	Electric power generating system
EU	European Union
GEF	Global Environmental Facility
GWe	Gigawatts-electrical
HCE	Heat collection elements
HRSG	Heat recovery steam generator
HTF	Heat transfer fluid
HTGR	High-temperature gas-cooled reactor
IEA	International Energy Agency
IGC	Intergranular corrosion
ILR	Intermediate load range
IPP	Independent power producer
IRD	Industrial Research & Development
IRR	Internal rate of return
ISCCS	Integrated Solar Combined Cycle System (s)
km	Kilometers
kPa	Kilopascals
kW	Kilowatts

ACRONYMS AND ABBREVIATIONS

Term	Definition or Clarification
kWt	Kilowatts-thermal
LCOE	Levelized costs of energy
LEC	Levelized energy cost
MACRS	Modified Accelerated Cost Recovery System
MW	Megawatts
MWe	Megawatts-electrical
MWt	Megawatts-thermal
NRC	National Research Council
NREL	National Renewable Energy Laboratory
O&M	Operation and maintenance
PR	Progress ratio
PTC	Energy Production Tax Credit
PV	Photovoltaic
R&D	Research and development
Sargent & Lundy or S&L	Sargent & Lundy LLC
SCA	Solar collector assembly
SEGS	Solar Electric Generating Station
SNL	Sandia National Laboratories
SunLab	SunLab comprises researchers from Sandia National Laboratories and the National Renewable Energy Laboratory working together on Concentrating Solar Power technology for the Department of Energy
TES	Thermal energy storage

ACKNOWLEDGEMENTS

Sargent & Lundy would like to thank the following individuals and organizations for their important contributions to this study:

R. D. (Dale) Rogers	Boeing
Robert Litwin	Boeing
Pat DeLaquil	Clean Energy Commercialization
Frank Wilkins	Department of Energy
Gilbert Cohen	Duke Solar
David Kearney	Kearney & Associates
Mark Mehos	National Renewable Energy Laboratory
Fredrick Morse	Morse Associates, Inc.
Henry Price	National Renewable Energy Laboratory (SunLab)
William Gould	Nexant
Scott Jones	Sandia National Laboratories (SunLab)

EXECUTIVE SUMMARY

PURPOSE AND SCOPE

A review of DOE's Renewable Energy Programs by the National Research Council in 2000 (*Renewable Power Pathways: A Review of the U.S. Department of Energy's Renewable Energy Programs, NRC-2000*) recommended that DOE "*should limit or halt its R&D on power-tower and power-trough technologies because further refinements to these concepts will not further their deployment*." Subsequent DOE funding requests for Concentrating Solar Power (CSP) technology development have been sharply reduced (FY02, FY03) or zero (FY04). In 2002, DOE's Office of Energy Efficiency and Renewable Energy (DOE/EERE) conducted a Strategic Program Review that, among other things, identified a need for further technical analysis of CSP R&D. In response, DOE/EERE initiated a review process whereby an independent engineering firm would conduct a detailed analysis of CSP, which would in turn be reviewed by a second independent NRC panel.

Sargent & Lundy LLC (S&L) was selected by DOE/EERE to conduct this independent "due-diligence-like" analysis of parabolic trough and power tower solar technology cost and performance. The work by S&L was done in close collaboration with the National Research Council (NRC) Committee, which was contracted by DOE/EERE to provide this second level of independent review.

As detailed below, S&L's analysis of the cost-reduction potential of CSP technology over the next 10–20 years included the following:

- Examination of the current trough and tower baseline technologies that are examples of the next plants to be built, including a detailed assessment of the cost and performance basis for these plants.
- Analysis of the industry projections for technology improvement and plant scale-up out to 2020, including a detailed assessment of the cost and performance projections for future trough and tower plants based on factors such as technology R&D progress, economies of scale, economies of learning resulting from increased deployment, and experience-related O&M cost reductions resulting from deployments.
- Assessment of the level of cost reductions and performance improvements that, based on S&L experience, are most likely to be achieved, and a financial analysis of the cost of electricity from such future solar trough and tower plants.

SARGENT & LUNDY CONCLUSIONS

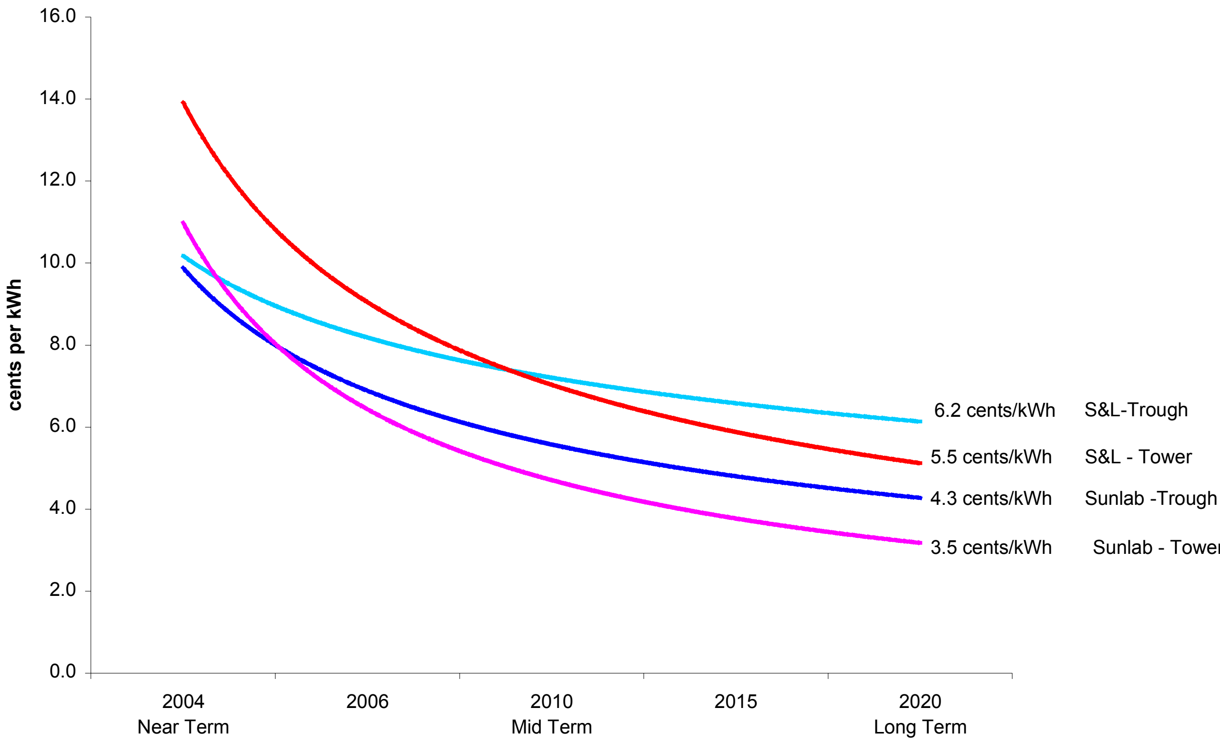
Based on this review, it is S&L's opinion that CSP technology is a proven technology for energy production, there is a potential market for CSP technology, and that significant cost reductions are achievable assuming reasonable deployment of CSP technologies occurs. S&L independently projected capital and O&M costs, from which the levelized energy costs were derived, based on a conservative approach whereby the technology improvements are limited to current demonstrated or tested improvements and with a relatively low rate of deployment (this does not mean that there is no technology development, only that the technologies have been demonstrated or tested at some scale so that no breakthroughs are required; further scale-up and engineering are required with associated risks).

The projections for electrical power consumption in the United States and worldwide vary depending on the study, but there will be a significant increase in installed capacity due to increased demand through 2020. Trough and tower solar power plants can compete with technologies that provide bulk power to the electric utility transmission and distribution systems if market entry barriers are overcome:

- Market expansion of trough and tower technology will require incentives to reach market acceptance (competitiveness). Both tower and trough technology currently produce electricity that is more expensive than conventional fossil-fueled technology. Analysis of incentives required to reach market acceptance is not within the scope of the report.
- Significant cost reductions will be required to reach market acceptance (competitiveness). S&L focused on the potential of cost reductions with the assumption that incentives will occur to support deployment through market expansion.

For the more technically aggressive low-cost case, S&L found the National Laboratories' "SunLab" methodology and analysis to be credible. The projections by SunLab, developed in conjunction with industry, are considered by S&L to represent a "best-case analysis" in which the technology is optimized and a high deployment rate is achieved. The two sets of estimates, by SunLab and S&L, provide a band within which the costs can be expected to fall. The figure and table below highlight these results, with initial electricity costs in the range of 10 to 12.6 ¢/kWh and eventually achieving costs in the range of 3.5 to 6.2 ¢/kWh. The specific values will depend on total capacity of various technologies deployed and the extent of R&D program success. In the technically aggressive cases for troughs / towers, the S&L analysis found that cost reductions were due to volume production (26%/28%), plant scale-up (20%/48%), and technological advance (54%/24%).

Figure ES-1 — Levelized Energy Cost Summary



Sargent & Lundy allocated cost reduction as follows:

	S&L High-Cost Bound	Cumulative Deployment 2002–2020	SunLab Low-Cost Bound	Cumulative Deployment 2002–2020
Troughs	6.2 cents/kWh	2.8 GWe	4.3 cents/kWh	4.9 GWe
Towers	5.5 cents/kWh	2.6 GWe	3.5 cents/kWh	8.7 GWe

Trough technology is further advanced than tower technology. Trough technology has 354 MW of commercial generation in operation in the southwestern United States. Tower technology has been successfully demonstrated with a conceptual and pilot plants (Solar One and Solar Two). Trough technology is a fully mature technology, and there is low technical and financial risk in developing near-term plants. The long-term projection has a higher risk due to technology advances needed in thermal storage. The tower technology needs to proceed from demonstration to commercial development. There is a higher technical and financial risk in developing a first-of-its-kind commercial plant. The advantage of tower technology is that if commercial development is successful (e.g., if expected cost and performance targets are achieved), then the levelized energy cost (LEC) for long-term deployment will be less than for trough technology.

TROUGH TECHNOLOGY

Trough Technology Summary

The cost, performance, and risk of parabolic trough technology are fairly well established by the experience of the existing operating parabolic trough plants. Based on the data available to S&L, the analysis bounds the future potential cost of parabolic trough power.

- Assuming the technology improvements are limited to current demonstrated or tested improvements and a deployment of 2.8 GWe of installed capacity by the year 2020 and successful development of a thermal storage system, trough costs should be able to drop to approximately 6.2¢/kWh
- Assuming the projected technical improvements are achieved by an active R&D program combined with incentives and deployment of 4.9 GWe, the trough costs projected by Sunlab of about 4¢/kWh could be acheived.

Trough Technology S&L Base Case

The base case for the S&L trough technology cost estimates is as follows:

	Trough
Year	2020
Capacity, MWe	400
Capacity Factor, %	56.2%
Capital Cost, $/kW	$3,220
Annual O&M Cost, $k	$14,129
Levelized Energy Cost (LEC), $/kWh	$0.0621
Economic Life	30 yrs
General Inflation	2.5 %
Equity Rate of Return	14%
Cost of Construction	7%
Construction Duration	1 yr.
Investment Tax Credit	10%
Taxes	40.2%
Depreciable Life	5 yrs.
Internal Rate of Return (IRR)	14%
Debt Service Coverage Ratio (DSCR)	1.35
Ownership	IPP

Differences and Rational for the S&L Trough Technology Projection

The DOE Concentrating Solar Power Program has developed detailed baseline cost and performance data for the parabolic trough technology. In addition, detailed technology R&D plans specify how these technologies are expected to change over time. DOE also has established assumed plant deployment forecasts over time. The S&L due-diligence-like approach used in this study reviewed the technology cost, performance, technology R&D, and deployment assumptions and identified the areas where the assumptions have not been fully demonstrated. The S&L review was based on discussions with SunLab, interaction with the CSP industry, input from other experts, and S&L in-house technical expertise.

Relatively detailed cost and performance data are available from existing operating parabolic trough power plants. As a result, near-term estimates are relatively close between the SunLab case and the S&L case. In the longer-term (2020), the S&L projection differs from the SunLab trough cases in several key areas. A more conservative estimate of improvements in annual solar-to-electric efficiency is used, a less aggressive estimate in collector cost reductions due to lower expected deployments, and a somewhat higher O&M cost.

The projected levelized energy cost of electricity in 2020 estimated by S&L is 45% higher than the SunLab case. The main differences and rational for the S&L projections are the following:

- The annual solar-to-electric efficiency in the S&L case is lower than the SunLab case for the following reasons (SunLab 17.2%, S&L 15.5%)
  - Receiver performance based on demonstrated UVAC technology. Absorption of 94.4% (SunLab 96%), envelop transmittance of 96.5% (SunLab of 97%), and emittance of 10% at 400C (SunLab 7%).
  - Mirror reflectivity efficiency was not increased beyond the demonstrated value of 93.5% (SunLab 95%). Increase would require advanced glass or other reflective membranes.
  - Mirror cleanliness efficiency was not increased beyond the demonstrated value of 95% (SunLab 96%). Increase would require new materials and significant enhancements in cleaning equipment and methods.
- The capital cost in the S&L case is 45% higher than the SunLab case for the following reasons. (SunLab $2,221/kWe, S&L $3,220/kWe)
  - The lower S&L solar-to-electric efficiency requires a larger solar field to compensate. The S&L case assume an 11% increase in solar field.
  - The S&L case assumes a lower deployment 2.8 GWe by 2020 verses the SunLab deployment assumption of 4.8 GWe. As a result, less production-based learning was assumed.
  - Cost estimates for steam turbines and balance-of-plant costs were estimated by S&L using the EPRI SOAPP model, compared to S&L's internal cost database, and adjusted for labor and productivity rates in the southwestern states. The S&L estimates for steam turbines were less than SunLab. The S&L estimates for balance-of-plant costs were comparable to SunLab.

- S&L estimated that the engineering, management, and development to be 15% of the capital cost as compared to SunLab estimate of 7.8%.

- Sargent & Lundy's estimate of the O&M costs is higher than SunLab for the following reasons:
  - S&L scaled-up the cost of field and vehicle maintenance to account for the increase in field size
  - Raw water cost used by S&L is based on actual cost reports at SEGS of $0.00122 per gallon ($0.32 per m^3). SunLab estimated the cost to be $0.021 per m^3, which is about 15 times less than the S&L estimate.

Trough Technology Cost Sensitivity

Variations in the inputs for levelized energy costs were calculated to illustrate the sensitivity to variations.

	LEC	Variation
Sargent & Lundy Base Case for 2020	$0.0621/kWh	
Financial Incentives		
Impact of Eliminating 5-year MACRS	$0.0698	12.5%
Impact of Eliminating 10% Investment Tax Credit (ITC)	$0.067	7.8%
Replacing ITC with Production Tax Credit of 1.8¢/kWh	$0.049	-26.9%
Project Cost		
Increasing Cost of Equity by 1%	$0.0668	7.7%
Increasing Construction Period to 2 Years	$0.0655	5.5%
Increase in Capital Cost by 10%	$0.0675	8.8%
Increase in Annual O&M Cost by 20%	$0.0635	2.3%
Ownership		
Utility Ownership	$0.0597	-3.9%
Municipal Utility Ownership	$0.0458	-26.1%
Technology & Deployment		
Increased Deployment from 2.8 GWe to 4.9 GWe	$0.0593	-4.7%
Advanced Technology Case	$0.0534	-16.3%

Trough Technology Risk Analysis

The major risk for parabolic trough solar plants to reach market acceptance (competitiveness) is the incentives that will allow the plant to be competitive with current non-renewable cost of generating power. Assuming incentives are provided the risk for achieving cost reduction over the next 10 – 20 years is low to average.

The capital cost estimate for the initial deployment was developed by SunLab based on actual costs for the SEGS plants, detailed cost models developed by industry, and spare part data for the SEGS plant. S&L reviewed published cost data and updated the information to include the latest cost estimate for receivers from Solel, mirrors from FlagSol, collector structure costs from EuroTrough and Duke Solar, electrical power generation system and balance-of-plant costs from the EPRI SOAPP program and S&L's internal database, and increased contingencies. The S&L estimate is 15% higher than the SunLab estimate, which is within an acceptable range.

Cost reductions are achieved from technology improvements, economy of scale, and volume production. The risk of achieving the technology improvements projected by S&L is low based on field-demonstrated technology at the SEGS plants and ongoing research by Duke Solar, Solel, FlagSol, and others. The one technology risk element left in the S&L case was the switch to molten-salt heat transfer fluid (HTF), which is key to driving down future costs. This switch adds some additional risk to the technology. A parametric case is included that assumes no thermal storage to see the impact of this technology.

Economy of scale is a well-established method of estimating the cost of components of a new size or quantity from the known cost for a different size or capacity. The risk of achieving the cost improvements projected by S&L from economy of scale is low based on (a) using well-established scaling factor ratios from industry data (e.g. balance-of-plant, receivers, and electric power system) or (b) if no data are available, then using scaling factors slightly more conservative than the industry average. The risk of achieving the cost improvements from volume production projected by S&L is low based on the cost reduction experience from the SEGS plants.

Key Trough Technology Conclusions

A number of key technology advances will cause near-term trough plants to be a significant improvement over the SEGS units. These include:

- Development of the new Solel UVAC receiver, improving collector field thermal performance by 20%.
- Development of a near-term thermal storage option for troughs by Nexant and SunLab. The design is likely to be demonstrated at the first trough plant to be built in Spain.
- Replacement of flex hoses with ball joint assemblies in the collector field, significantly reducing HTF pumping parasitics and increasing the potential size of future parabolic trough solar fields.

The development of longer-term, more advanced thermal storage technologies is critical. This path offers the largest cost reduction potential, as follows.

- Integral with advanced thermal storage is the implementation of a higher temperature heat transfer fluid in the 450°–500°C range. (SunLab and international R&D groups have significant efforts underway.)

- However, increasing trough-operating temperature to 500°C appears to have minimal impact on the eventual LEC compared to 450°C. This is contrary to earlier conclusions, necessitating a more detailed assessment in the near future.

Significant cost reductions appear reachable in all three key trough components—structure, receiver, and reflectors—though brought about by different cost reduction mechanisms.

- Concentrator cost reduction will depend largely on size scale-up, production volume, and increased competition. (Significant industrial efforts are currently in progress by Duke Solar & EuroTrough.)
- Alternative reflector (mirror) options and production volume are projected to drop costs significantly.
- Achieving an operating temperature of 450°C with current receiver technology appears feasible. However, the development of a higher performing and more reliable receiver is very important to achieve SunLab long-term cost and performance goals (labs and industry are addressing this).

O&M procedures are expected to continue downward with scale-up, increasing field experience, and technology improvements in reliability.

TOWER TECHNOLOGY

Tower Technology Summary

Because no commercial power tower plants have been built, there is more uncertainty in the cost, performance, and technical risk of this technology. Based on the data available to S&L, the analysis bounds the future potential cost of power tower plants.

- Assuming the technology improvements are limited to current demonstrated or tested improvements and a deployment of 2.6 GWe of installed capacity by the year 2020, tower costs should be able to drop to approximately 5.5¢/kWh
- Assuming the projected technical improvements are achieved by an active R&D program combined with incentives and deployment of 8.7 GWe, the tower costs projected by Sunlab of about 3.5¢/kWh could be achieved.

Tower Technology S&L Base Case

The base case for the Sargent & Lundy tower technology cost estimates is as follows:

	Tower
Year	2020
Capacity, MWe	200
Capacity Factor, %	72.9%
Capital Cost, $/kW	$3,622
Annual O&M Cost, $k	$9,132
Levelized Energy Cost (LEC), $/kWh	$0.0547
Economic Life	30 yrs
General Inflation	2.5 %
Equity Rate of Return	14%
Cost of Construction	7%
Construction Duration	1 yr.
Investment Tax Credit	10%
Taxes	40.2%
Depreciable Life	5 yrs.
Internal Rate of Return (IRR)	14%
Debt Service Coverage Ratio (DSCR)	1.35
Ownership	IPP

Differences and Rational for the S&L Tower Technology Projection

The DOE Concentrating Solar Power Program has developed detailed baseline cost and performance data for the power tower technology. In addition, detailed technology R&D plans specify how these technologies are expected to change over time. DOE also has established assumed plant deployment forecasts over time. The S&L due-diligence-like approach used in this study reviewed the technology cost, performance, technology R&D, and deployment assumptions and identified the areas where the assumptions have not been fully demonstrated. The S&L review was based on discussions with SunLab, interaction with the CSP industry, input from other experts, and S&L in-house technical expertise.

The projected levelized energy costs of electricity in 2020 estimated by S&L are 65% higher than the projections by SunLab. The main differences and rational for the S&L projections are the following:

- Sargent & Lundy did not assume deployment of the advanced high temperature turbine and heliostats in 2020, whereas the SunLab assumed deployment in 2018.

- Sargent & Lundy cost estimate for heliostats, which are about 45% of the total cost, are about 10% higher. The S&L estimate is based on our evaluation of cost estimates prepared by SunLab, AD Little, Advanced Thermal Systems, Solar Kinetics, and Winsmith.
  - S&L used a contingency of 10% as compared to SunLab of 5%.
  - S&L estimated deployment at about 25% of the SunLab estimate to take into consideration a realistic duration between the first and second deployment and between increases in plant size.
  - S&L manufacturing costs are higher as a result of our evaluation
- Sargent & Lundy estimated the costs for steam turbines and balance of plant costs using the EPRI SOAPP model, compared to S&L's internal cost database and adjusted for labor and productivity rates in the southwestern states. The S&L estimate for steam turbines were less than SunLab. The S&L estimates for balance-of-plant costs were higher than SunLab.
- The S&L receiver capital costs are based on a cost estimate provided by Boeing. Boeing was the supplier of the Solar Two receiver and is providing the receiver for Solar Tres.
- Sargent & Lundy estimated that the engineering, management, and development to be 15% of the capital cost as compared to SunLab estimate of 7.8%.
- SunLab included a risk pool contingency of 10% for Solar Tres, and S&L concurs with this value. In addition, S&L included a risk pool contingency of 5% for Solar 50.
- S&L included a contingency of 12% for direct costs and 15% for cost reduction, in comparison to SunLab's contingency of 7.8%
- The efficiency projections by S&L were based on a review of the SunLab Reference Case, demonstrated efficiencies, design modifications based on lessons learned from Solar Two, and turbine generator computer model. The main differences are the following:
  - Mirror reflectivity efficiency was not increased beyond the demonstrated value of 95%. Increase would require advanced glass or other reflective membranes.
  - Mirror cleanliness efficiency was not increased beyond the demonstrated value of 95%. Increase would require new materials and significant enhancements in cleaning equipment and methods.
  - Near-term efficiencies were based on the ABB-Brown Boveri heat balance for SEGS IX. The efficiency for other size units was verified by using the General Electric STGPer software program.
  - Efficiency has a direct impact on the size of the collector field. The increase in collector field area and corresponding increase in capital cost was calculated based on the lower efficiency estimated by S&L.
- S&L estimate of the O&M costs is higher than SunLab for the following reasons:
  - S&L scaled-up the cost of field and vehicle maintenance to account for the increase in field size.
  - S&L assumed that the average burdened rate would not decrease between Solar 100 and Solar 220.

— Raw water cost used by S&L is based on actual cost reports at SEGS of $0.00122 per gallon ($0.32 per m^3). SunLab estimated the cost to be $0.021 per m^3), which is about 15 times less than the S&L estimate.

— S&L included a 10% contingency.

Tower Technology Cost Sensitivity

Variations in the inputs for levelized energy costs were calculated to illustrate the sensitivity to variations.

	LEC	Variation
S&L Base Case for 2020	$0.0547/kWh	
Financial Incentives		
Impact of Eliminating 5-year MACRS	$0.0614	12.3%
Impact of Eliminating 10% Investment Tax Credit (ITC)	$0.0590	7.8%
Replacing ITC with Production Tax Credit of 1.8¢/kWh	$0.0410	-30.5%
Project Cost		
Increasing Cost of Equity by 1%	$0.0588	7.6%
Increasing Construction Period to 2 Years	$0.0577	5.4%
Increase in Capital Cost by 10%	$0.0595	8.7%
Increase in Annual O&M Cost by 20%	$0.0561	2.6%
Ownership		
Utility Ownership	$0.0526	-3.8%
Municipal Utility Ownership	$0.0406	-25.7%
Technology & Deployment		
Increased Deployment from 2.6 GWe to 8.7 GWe	$0.0524	-4.2%
Advanced Technology Case with Advanced Heliostat and High Temperature Turbine-Generator (from 16.5% to 17.4%)	$0.0487	-11.0%
Worst Case Efficiency (from 16.5% to 14.6%)	$0.0590	7.9%

Tower Technology Risk Analysis

The major risk for tower solar plants to reach market acceptance (competitiveness) is the incentives that will allow the plant to be competitive with current non-renewable cost of generating power. Assuming incentives are provided, the risk for achieving cost reduction over the next 10–20 years is low to average.

The capital cost estimate for the initial deployment was developed by SunLab based on actual costs for Solar Two, the Central Receiver Utility Studies, the AD Little heliostat detailed cost estimate, detailed heliostat design from ATS, and industry data. S&L reviewed published cost data and updated the information to include the latest cost estimate for receivers from Boeing, electrical power generation system and balance-of-plant costs from the EPRI SOAPP program and S&L's internal database, and increased contingencies. The S&L estimate is 15% higher than the SunLab estimate, which is within an acceptable range.

Cost reductions are achieved from technology improvements, economy of scale, and volume production. The risk of achieving the technology improvements projected by S&L is low based on demonstrated technology, design enhancements from lessons learned during Solar Two, improved advances in control technology since Solar Two, and ongoing research by Boeing. Economy of scale is a well-established method of estimating the cost of components of a new size or quantity from the known cost for a different size or capacity. The risk of achieving the cost improvements projected by S&L from economy of scale is low based on (a) using well-established scaling factor ratios from industry data (e.g. balance of plant, receivers, and electric power system) or (b) if no data are available, then using scaling factors slightly more conservative than the industry average. The risk of achieving the cost improvements from volume production projected by S&L is low based on using a progress ratio of 0.97, which is at the upper end of published data. Various studies on learning curves from actual data suggest a progress ratio of 0.82 for development of photovoltaics and 0.95 for development of wind power.

Key Tower Technology Conclusions

Solar plant and power plant scale-up provide the largest cost reduction opportunity for power tower technologies.

- Scale-up of the tower solar plant requires a total redesign and re-optimization of the field, tower, and receiver. This greatly reduces capital and O&M costs, but has only a small effect on efficiency. R&D support in the design, development, and testing of larger receivers, larger heliostats, and larger heliostat fields will reduce scale-up risk.
- Scale-up of the steam turbine increases efficiency, and reduces capital and O&M costs. Probability of success here is very high, as no development is required until high-efficiency supercritical steam turbines become available (2020).

Key technical advances include increasing receiver solar flux levels, development of new heliostat designs with significantly lower costs, and the use of new highly efficient steam turbines.

- Increased receiver flux levels have been demonstrated at the prototype scale and require improved heliostat field flux monitoring/management systems and design optimization for use at large plants.

- Revolutionary heliostat designs with significantly lower cost have been proposed that use flexible, durable thin mirrors with a lower-weight ‘stretched-membrane’ design that can be manufactured in high volumes. Other novel designs like inflatable/rolling heliostats are also possible.
- High-efficiency supercritical steam turbines are now being demonstrated that operate at temperatures compatible with current tower technology or at temperatures that require increasing the operating temperature of the tower technology to 600°–650°C.

The major volume manufacturing benefit evaluated for tower technology was related to heliostats.

- Heliostat cost reduction will occur when they are produced at high volume. Sargent & Lundy’s evaluation of the current heliostat design and cost indicated that cost should decrease 3% with each doubling of cumulative capacity. This would reduce the cost of a field of 148 m^2 heliostats from $\$148/m^2$ to $\$94/m^2$.

DISCUSSION OF NRC COMMENTS ON THE S&L DRAFT REPORT

The draft report of the S&L “due-diligence-like” analysis of parabolic trough and power tower solar technology cost and performance was reviewed the National Research Council Committee. The results of the NRC review were published in “Critique of the Sargent & Lundy Assessment of Cost and Performance Forecasts for Concentrating Solar Power.” The NRC Committee recommended several methodological approaches for S&L to follow, identified areas for further investigation by S&L, and critically reviewed the S&L findings.

Much of the NRC critique of the S&L analysis centered around assumed rates of deployment and incentive issues. Deployment and incentive issues were outside the scope of work for S&L. As noted by the NRC: “The committee notes that CSP technology is not unique in the requirement for incentivizing the early market phases of emerging energy technologies” (NRC, page 11). “The committee notes the extensive reports and study literature on these issues cited by S&L, including DOE/EERE’s own August 2002 Report to Congress on the Feasibility of 1,000 Megawatts of Solar Power in the Southwest by 2006…” (NRC, page 11). DOE noted in their presentations to the NRC and S&L that because such studies were available, DOE’s primary concern, and the reason for this study, was to determine the potential technical feasibility of CSP. Nevertheless, there are several deployment issues worth considering. First, the “chicken-and-egg” (NRC, page 15) problem of driving down costs by deploying technologies, but facing high initial costs that impede deployment, is true of all energy technologies, not just CSP. Second, as noted by the NRC and S&L, incentives are a key determinant of the rate at which CSP, or any new energy technology, penetrates the market. Evaluating this lies well outside the technical analysis requested of S&L. Third, the level of deployment identified by S&L is modest, at about 2.8 GW by 2020. The NRC also noted that “The SunLab deployment scenarios evaluated by S&L represent a range from a modest rate of adding one 100 MWe plant per year (the first becoming operational in 2004) to an aggressive approach that would result in almost 5,000 MWe of new capacity by 2020” (NRC, page 5). To place this in context, the wind industry added 1,700 MW of new capacity in the U.S. in 2001 alone.

The main NRC findings that support the S&L study are the following:

1. The NRC committee believed that a plausible estimate of levelized energy cost would lie somewhere between S&L's and Sunlab's projections in 2020.

    - "Based on the level of uncertainty that is inherently present in projecting these deployment rates and technology advances, a more plausible estimate would lie somewhere between the two projections (S&L's and SunLab's) in 2020. However, if deployment does not proceed at the assumed rate, the projected LEC could be much higher than either of these estimates." (NRC page 6)

2. The NRC committee agreed with S&L on a number of its technical findings.

    - "Since 1999, significant progress has been made in understanding the potential impacts of thermal storage technologies, thin film glass mirrors, improved heat collection units, improved trough support structures, and other technical opportunities to improve CSP technology." (NRC Page 4)
    - "The committee agrees with S&L's identification of key technology components for increasing the performance of trough systems to lower costs." (NRC, page 6)
    - The committee has a high confidence in the estimate for power block cost reductions that will result in increasing plant sizes. (NRC, pages 7 and 8)
    - "The committee believes that S&L did a reasonable job of assessing the improvements in annual tower efficiency of power plant progression.…" (NRC, page 7)
    - "It is anticipated that industry R&D will deliver the technical advances appropriate for receivers." (NRC, page 9)
    - "S&L appears to have done a reasonable job of assessing the design and capital cost potential for systems based on a near-term (or demonstrated) technologies." (NRC, page 8)
    - The NRC committee agreed with S&L's methods and review of the O&M costs. (NRC, page 5 and 9)

3. The NRC committee agreed with S&L that policy-based incentives are needed for initial introduction of technologies and that both R&D and deployment of technology are necessary.

4. The committee agreed that S&L's selection of the base case economic parameters are reasonable, but did not 'sufficiently examine the effect of uncertainties (NRC, page 5). S&L concurs with the NRC and has included expanded sensitivity analysis in the final report.

5. The NRC committee found that S&L was not biased and provided a creditable process within the constraints of time and the information available. Furthermore, the NRC committee stated that S&L did reasonable job assimilating information within time and resource constraints.

    - "…that S&L took any potential conflict of interest very seriously and made a concerted effort to address and avoid it. No obvious example of bias was apparent in S&L's interpretation of the available data nor was there any deliverate omission of pertinent facts. If anything, the S&L analysis was more conservative than SunLab's estimates in assessing areas like time to develop new materials or power conversion technologies." (NRC, page 18)

- "…that S&L attempted to maintain a credible process by filling in the gaps in its knowledge base with the advice of world-recognized experts." (NRC, page 18)

The main NRC committee recommendations to S&L are the following:

1. The NRC committee asked for a risk assessment. The S&L final report has been modified to include a risk assessment section per NRC recommendations.

2. The NRC committee asked for additional sensitivity analysis. The S&L final report has been modified to include an expanded sensitivity analysis per NRC recommendations.

3. The NRC committee asked for clarification of the differences and rational for the S&L cost estimate. The S&L final report has been modified to include a comparison summary of the differences in the executive summary.

4. The NRC committee would have preferred a bottoms-up cost analysis. This study was never intended to provide a bottoms-up cost assessment. Unfortunately time and budgets did not allow for this type of cost analysis. Instead, a typical financial review was conducted to assess the validity of the existing data.

A considerable portion of the NRC's critique was focused on the S&L scope of work, not results of our review as documented in the report. Sargent & Lundy had a defined scope of work for this project, which was clearly identified in our contract. Most of the areas identified by the NRC as a critique to the S&L Report are in fact critiques of the defined work scope. The most significant areas identified by the NRC, which were not in our scope of work, are the following:

- The type or value of incentives needed to reach market acceptance. Our report clearly identifies that this was not part of the work scope and is one of the most significant market entry barriers to overcome.

- The S&L projection of deployment is 'not creditable'. The scope of work did not include a market analysis, which would be required to provide a deployment projection. One of the key drivers for deployment is overcoming market entry barriers, in particular incentives. As previously mentioned, incentives are needed, but the political climate and assessment of whether or when incentives would become available require significant review not considered within our scope.

- Power generation market. The S&L draft report issued September 2002 included a discussion of power generation markets, including geography, access to established power grids, environmental restrictions or incentives, and taxes. Subsequently, due to a tight schedule and because such work had already been done elsewhere, the DOE directed that the scope of work not include an evaluation of the power generation market and associated issues.

- The S&L report did not include a bottoms-up cost estimate. Our scope of work was an independent review of the cost estimates developed by SunLab for trough and tower technology. It is typical for due diligence or due diligence-like reviews to perform an independent assessment of cost estimates and documentation provided for our review and to point out areas where the estimates may be inaccurate. Typically, this type of review does not include an independent bottoms-up cost estimate. Instead, S&L drew heavily from industry experience, vendor quotes, and other sources rather than recreate all this analysis on its own.

Sargent & Lundy agrees that the recommended expanded scope proposed by the NRC provides additional value to the DOE. However, we believe the methodology used by S&L stands on its own as a credible assessment of the status and potential of parabolic trough and power tower technologies. Sargent & Lundy's response to the more significant findings in the NRC critique is included in Appendix I.

Appendix A
List of Documents

A. LIST OF DOCUMENTS

FROM FULL REPORT

This list contains both the documents cited in footnotes in the text and other documents reviewed for the report. Document references followed by a number in parenthese are included on the attached compact disk, keyed to that number.

Advanced Thermal Systems, Inc., 1996. Solmat Phase 1 Final Review, Model H-150 Heliostat Design, May 15, 1996

AeroVironment, Inc., 1995. “Fugitive Emissions Testing - Final Report,” for KJC Operating Company, Monrovia, California, January 1995.

Akhil, A.A., S.K. Swaminathan, and R.K. Sen, 1997. Cost Analysis of Energy Storage for Electric Utility Applications, Sandia National Laboratories: February 1997. Report SAND97-0443.

Alpert, D.J., and G.J. Kolb, 1988. Performance of the Solar One Power Plant as Simulated by the SOLERGY Computer Code, Sandia National Laboratories, Albuquerque, NM: 1988. Report SAND88-0321.

Anderson, 1998. The Economics of Photovoltaic Technologies.

Anderson, D. and K. Ahmed, 1995. The Case for the Solar Energy Investments, World Bank Technical Paper Number 279 - Energy Series, World Bank, Washington D.C.: February 1995. ISBN 0-8213-3196-5.

Arthur D. Little, Inc., 2001. “Heliostat Cost Review,” June 2001. (87)

ASME, 2001. “EUROTROUGH Design Issues And Prototype Testing At PSA,” Proceedings of ASME International Solar Energy Conference - Forum 2001, Solar Energy.

Bechtel National Inc., 1995. “Central Receiver Commercialization Plan,” for the California Energy Commission: June 1995. Report 01-0444-35-3027-2777.

Boeing, Roadmap: Power Tower Receiver System (not publicly available).

Boer, Karl W., ed., 1997. Advances in Solar Energy - An Annual Review of Research and Development, Volume 11, Chapter 1, article by Mancini, T.R., M.R. Prairie, and G.J. Kolb, American Solar Energy Society, Inc., Boulder, CO, 1997. ISBN 0-89553-254-9.

Central Receiver Utility Studies, 1989. A series of reports prepared by Pacific Gas and Electric (and its principal subcontractor, Bechtel National, Inc.) and Arizona Public Service (and its principal subcontractor, Black and Veatch Engineers-Constructors) cofunded by the U.S. Department of Energy, the Electric Power Research Institute, and the utilities themselves.

Chiang, C. J., 1987. SUNBURN: A Computer Code for Evaluating the Economic Viability of Hybrid Solar Central Receiver Electric Power Plants, Sandia National Laboratories, Albuquerque, NM: June 1987. Report SAND86-2165.

Christiansson, L., 1995. Diffusion and Learning Curves of Renewable Energy Technologies. Working Paper WP-95-126. International Institute for Applied Systems Analysis. Laxenburg, Austria. [Note: Christiansson is Neij's maiden name.]

Cohen, G., and S. Frier, 1997. "Ten Years of Solar Power Plant Operation in the Mojave Desert," Proceedings of Solar 97, the 1997 ASES Annual Conference, Washington, D.C. (April 1997).

Dahl, Jaimee, Karen Buechler, Alan Weimer, Allan Lewandowski, and Carl Bingham, 2002. "Rapid Solar-thermal Dissociation of Natural Gas in an Aerosol Flow Reactor," 11th SolarPACES International Symposium on Concentrated Solar Power and Chemical Energy Technologies, Zurich, Sep 4-6, 2002.

Dudley, V., G. Kolb, A. R. Mahoney, T. Mancini, C. Matthews, M. Sloan, and D. Kearney, 1994. Test Results: SEGS LS-2 Solar Collector, Sandia National Laboratories, Albuquerque, New Mexico: December 1994. Report SAND94-1884.

Duke Solar, 2000. ''Task 2 Report: New Space-Frame Parabolic Trough Structure,'' Prepared for NREL by Duke Solar, Raleigh, NC.

Durstewitz, M., 1999. Using information of Germany's "250 MW Wind" Programme for the construction of Wind power experience curves. Proceedings of the IEA International Workshop "Experience Curves for Policy Making: The case of energy technologies," Stuttgart, Germany, 10-11 May.

EERE, 2002. "Feasibility of 1,000 Megawatts of Solar Power in the Southwest by 2006." (06)

Electric Power Research Institute (EPRI). State of the Art Power Plant (SOAPP) computer program: developed, distributed, and supported by EPRI.

Energy Information Administration, 2002. “Annual Energy Outlook 2002 with Projections to 2020,” U.S. Department of Energy.

Energy Information Administration, 2002. “International Energy Outlook 2002,” U.S. Department of Energy.

Enermodal Engineering Limited, 1999. “Cost Reduction Study for Solar Thermal Power Plants,” prepared for the World Bank. (11)

Falcone, P.K., 1986. A Handbook for Solar Central Receiver Design, Sandia National Laboratories, Livermore, CA: December, 1986. Report SAND86-8009.

Flachglas Solartechnik GmbH, 1994. “Assessment of Solar Thermal Trough Power Plant Technology and Its Transferability to the Mediterranean Region - Final Report,” for European Commission Directorate General I External Economic Relations, and Centre de Developpement des Energies Renouvelables and Grupo Endesa, Cologne, Germany: June 1994.

Gee, R., G. Cohen, and R. Winston, 2002. “A Non-Imaging Receiver for Parabolic Trough Concentrating Collectors,” Proceedings of Solar 2002. (16)

Gorman, D., 1993. “Heliostat Costs at Reduced Production Volumes - Report to Sandia National Laboratories,” Advanced Thermal Systems:

Hubbard, H., et al., 2000. Renewable Power Pathways; A Review of the U.S. Department of Energy’s Renewable Energy Programs, National Research Council, National Academy Press, 2000.

Humphreys, K.K., and L.M. English, 1993. *Project and Cost Engineers’ Handbook*, Third Edition, AACE International, Marcel Dekker, Inc., New York, 1993.

IEA, 2000. Experience Curves for Energy Technology Policy. International Energy Agency, Paris, France. (ISBN 92-64-17650-0).

Integrated Solar Combined Cycle Systems (ISCCS) 1996. Using Parabolic Trough Technology, Phase 1B Technical and Financial Review, Spencer Management Associates, Diablo, CA: March 1996, draft.

International Energy Agency, 2001a. "2000 Energy Technologies and Systems: A View to 2050," PCADT 1997, cited in Anderson 1998 as cited in the UK Project on Resource Productivity and Renewable Resource, Energy Technologies and Systems: A View to 2050, Part 1. Technical and Economic Potential of Generating Technologies, Draft May 4, 2001.

International Energy Agency, 2001b. "2000, Experience Curves for Energy Policy Assessment" as cited in the UK Project on Resource Productivity and Renewable Resource, Energy Technologies and Systems: A View to 2050, Part 1. Technical and Economic Potential of Generating Technologies, Draft May 4, 2001.

IST, 2001, "Collector Development," Presentation at Solar Forum 2001, Solar Energy.

Kearney, D., 2001a. Engineering Evaluation of a Molten Salt HTF in a Parabolic Trough Solar Field, Task 6 Report, Final System Performance and Cost Comparisons, August 20, 2001. (22.1)

Kearney, D., 2001b. "Engineering Evaluation of a Molten Salt HTF in a Parabolic Trough Solar Field," Task 7 Report, Recommendations on Development Needs, September 15, 2001. (22.2)

Kearney, D., and C. Miller, 1988. Solar Electric Generating System VI - Technical Evaluation of Project Feasibility, LUZ Partnership Management, Inc.: January 15, 1988.

KJC Operating Company, 1994, "O&M Cost Reduction in Solar Thermal Electric Power Plants - Interim Report on Project Status," for Sandia National Laboratories: September 1, 1994.

KJCOC, 1999. "O&M Cost Reduction Report," June. [Reference expanded in "Additional Information Sources" — see Cohen, G. E., D. W. Kearney, G. J. Kolb, 1999. Final Report on the Operation and Maintenance Improvement Program for Concentrating Solar Power Plants," SAND99-1290, Sandia National Laboratories, Printed June 1999. (24)]

Klenow, "Learning Curves and the Cyclical Behavior of Manufacturing Industries."

Kobos, P., 2002. "The Implications of Renewable Energy Research and Development: Policy Scenario Analysis with Experience and Learning Effects." Ph.D. thesis, Rensselaer Polytechnic Institute. (Forthcoming).

Kolb, G. J., 1995. "Evaluation of Power Production from the Solar Electric Generating Systems at Kramer Junction: 1988 to 1993", Solar Engineering - 1995, Proceedings of the ASME Solar Energy Conference, Maui, HI (March 19-24, 1995).

Kolb, G. J., 1996. “Economic Evaluation of Solar-Only and Hybrid Power Towers Using Molten Salt Technology”, Proceedings of the 8th International Symposium on Solar Thermal Concentrating Technologies, Cologne, Germany (October 6-11, 1996). Accepted for publication in the journal Solar Energy.

Kolb, G., J. Chavez, and W. Meinecke, 1993. “Second Generation Central Receiver Technologies: A Status Report,” M. Becker, and P. Klimas, eds., Verlag C.F. Muller Karlsruhe, DLR, and Sandia National Laboratories: 1993. Report ISBN 3-7880-7482-5.

Kouvaritakis, N., Soria, A., and Isoard, S., 2000. “Modeling Energy Technology Dynamics: Methodology for Adaptive Expectations Models with Learning by Doing and Learning by Searching.” Int. J. Global Energy Issues, Vol. 14, Nos. 1-4, pp. 104-115.

Kribus, A., P. Doron, R. Rubin, R. Reuven, E. Taragan, S. Duchan, and J. Karni, 2001. “Performance of the Directly Illuminated Annular Pressurized Receiver (DIAPR) Operating at 20 Bar and 1200 C,” 123:10-17, Journal of Solar Energy Engineering.

Lotker, M., 1991. “Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the LUZ Experience,” Sandia National Laboratories, Albuquerque, New Mexico: Report SAND91-7014. (10)

LUZ International Limited, 1990. “Solar Electric Generating System IX Technical Description,” LUZ International Limited.

Mackay, R.M. and S.D. Probert, 1998. “Likely Market-Penetration of Renewable-energy Technologies,” *Applied Energy*. Vol. 59, No. 1. pp. 1-38.

Marion, W., and S. Wilcox, 1994. “Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors,” National Renewable Energy Laboratory, Golden, Colorado: April 1994. Report NREL/TP-463-5607.

McDonald, A. and L. Schrattenholzer, 2001. “Learning Rates for Energy Technologies.” *Energy Policy*, Vol. 29, Issue 4, pp. 255-261, March.

Meinecke, W., and M. Bohn, 1995. “Solar Energy Concentrating Systems: Applications and Technologies,” edited by M. Becker, and B. Gupta, Muller Verlag, Heidelberg, Germany.

Moller, S., R. Buck, R. Tamme, M. Epstein, D. Liebermann, M. Meri, U. Fisher, A. Rotstein, and C. Sugarman, 2002. "Solar Production of Syngas for Electricity Generation: SOLASYS Project Test-Phase," 11th SolarPACES International Symposium on Concentrated Solar Power and Chemical Energy Technologies, Zurich, Sep 4-6, 2002.

Morales, A., and Ajona, J. I., 1998. ''Durability, Performance and Scalability of Sol-Gel Front Surface Mirrors and Selective Absorbers,'' Proc. of 9th International Symposium on Solar Thermal Concentrating Technologies.

Morse, Frederick H., 2000. "The Commercial Path Forward for Concentrating Solar Power Technologies: A Review of Existing Treatments of Current and Future Markets," Morse Associates, Inc., Washington D.C., December 13, 2000. (71)

Muller, M., 1994. "Direct Solar Steam in Parabolic Trough Collectors (DISS), Plataforma Solar de Almeria (PSA)," CIEMAT and DLR, May 1994, ISBN 84-605-1479-X.

National Construction Estimator, 49th Edition, erected structural steel for California.

National Research Council (NRC) Committee for the Review of a Technology Assessment of Solar Power Energy Systems, 2002. "Critique of the Sargent & Lundy Assessment of Cost and Performance Forecasts for Concentrating Solar Power," October 12, 2002 [Note the review was performed on Draft 3 of the Sargent & Lundy Report, SL-5641, dated October 2002] (80)

Neij, Lena, 1997. "Use of Experience Curves to Analyse the Prospects for Diffusion and Adoption of Renewable Energy Technology," *Energy Policy*, Vol. 23, No. 13, pp. 1099-1107, 1997. (70)

Neij, Lena, 1999. "Cost dynamics of wind power." *Energy*. Vol. 24, pp. 375-389.

Nextant Inc., 2001. USA Trough Initiative: Nitrate Salt Heat Transport Fluid Rankine Cycle, Steam Generator, and Thermal Storage Analysis, January 19, 2001.

O&M Cost Reduction in Solar Thermal Electric Power Plants - 2nd Interim Report on Project Status, KJC Operating Company, for Sandia National Laboratories: July 1, 1996.

Pacheco, J.E. (ed), G.J. Kolb, H.E. Reilly, S.K. Showalter, S.H. Goods, R.W. Bradshaw, D.B. Dawson, S.A. Jones, M.J. Hale, R.L. Gilbert, M.R. Prairie, and P. Jacobs, 2002. "Final Test and Evaluation Results from the Solar Two Project," SAND2002-0120, Sandia National Laboratories, Albuquerque, NM. (40)

Pacific Gas & Electric Company, 1988. “Solar Central Receiver Technology Advancement for Electric Utility Application, Phase 1 Topical Report,” San Francisco, CA: September 1988. Report 007.2-88.2.

PCADT 1997. “US President’s Committee of Advisors on Science and Technology report the President on Federal Energy Research and Development Challenges for the 21st Century.”

Peerless-Winsmith, Inc, 1989. “Development of a Low-Cost Drive Tracking Mechanism for Solar Heliostats or PV Arrays - Final Report,” for Sandia National Laboratories: February 1989. Report 90-5753.

Peerless-Winsmith, Inc., 1996. “Results of Dual Axis Solar Drive DFMA Workshop,” Contract ACG-5-15209-01, January 26, 1996. (88)

Peerless-Winsmith, Inc., 1999. “Enhanced Azimuth Solar Drive Project Summary Report,” for Sandia National Laboratories, Contract Number BF-0031, October 1999. (89)

Pilkington International, 1999. “Solar Steam System Investment Cost,” prepared for Midwest Research Institute, December 1999.

Pilkington Solar International, 1996. “Status Report on Solar Thermal Power Plants,” Report ISBN 3-9804901-0-6.

Price, H., E. Lüpfert, D. Kearney, E. Zarza, G. Cohen, R. Gee, and R. Mahoney, 2002. “Advances in Parabolic Trough Solar Power Technology,” Journal of Solar Energy Engineering, May 2002. (13)

Price, H., and Kearney, D., 1999. “Parabolic-Trough Technology Roadmap: A Pathway for Sustained Commercial Development and Deployment of Parabolic-Trough Technology,” NREL/TP-550-24748, NREL, Golden, Colorado. (14)

Radosevich, L., 1988. “Final Report on the Power Production Phase of the 10 MWe Solar Thermal Central Receiver Power Plant,” SAND87-8022, Sandia National Laboratories, Livermore, CA, March 1988.

Regional Economic Research, Inc., 1991. “Technical Potential of Alternative Technologies - Final Report,” for California Energy Commission, Contract No. 500-89-001, San Diego, CA: December 2, 1991.

Reilly, H.E., and G.J. Kolb, 2001. “An Evaluation of Molten-Salt Power Towers Including the Results of the Solar Two Project,” SAND2001-3674, Sandia National Laboratories. (39)

San Vicente, G., Morales, A., and Gutiérrez, M. T., 2001. "Preparation and Characterization of Sol-Gel TiO 2 Antireflective Coatings for Silicon."

Sandia National Laboratories, 2001. "Development of a Molten-Salt Thermocline Thermal Storage System for Parabolic Trough Plants," Proceeding of Solar Forum 2001.

Science Applications International Corporation, 1996. "Heliostat Cost Study for SOLMAT Program," for National Renewable Energy Laboratory, Golden, CO. (90)

Smith, D.C., and J.M. Chavez, A, 1988. "Final Report on the Phase 1 Testing of a Molten-Salt Cavity Receiver," Sandia National Laboratories, Albuquerque, NM: 1988. Report SAND87-2290.

Solar Kinetics, Inc., 1996. SolMatT, Mirror Module Assembly Plan and Cost Estimate. (91)

Stoddard, M.C., et al., 1987. "SOLERGY - A Computer Code for Calculating the Annual Energy from Central Receiver Power Plants," Sandia National Laboratories, Livermore, California: May 1987. Report SAND86-8060.

Strachan, J.W., and R.M. Houser, 1993. "Testing and Evaluation of Large-Area Heliostats for Solar Thermal Applications," Sandia National Laboratories, Albuquerque, NM: February 1993. Report SAND92-1381.

Sugarman, C., A. Ring, R. Buck, R. Uhlig, M. Beuter, M. J. Marcos, and V. Fernandez, 2002. "Solar-Hybrid Gas Turbine Power System," 11th SolarPACES International Symposium on Concentrated Solar Power and Chemical Energy Technologies, Zurich, Sep 4-6, 2002.

SunLab, 2001. Trough: DueDiligence11-Excelergy 11-14-01.xls.

SunLab, 2002. Tower: Tower Reference Case Aug 2.xls; Tower Costs.xls; and Heliostat Costs.xls.

Sutton, W.F., 1989. Prices of Drives at Different Production Volumes - Report to Sandia National Labs, Peerless-Winsmith, Inc.: April 4, 1989.

Swanekamp, R., 2002. "Return of the Supercritical Boiler," *Power*, Vol. 146, No. 4, July 2002.

Teagan, W. Peter, 2001. "Review: Status of Markets for Solar Thermal Power Systems," Arthur D. Little, Sandia Report SAND2001-2521P, May 2001. (92)

Tester J. et al., 2001. CSP Peer Review, December 7, 2001. (5.1)

UK Project on Resource Productivity and Renewable Resource, Energy Technologies and Systems: A View to 2050, Part 1. Technical and Economic Potential of Generating Technologies, Draft May 4, 2001.

Virtus Energy Research Associates, 1995. "Texas Renewable Energy Resource Assessment: Survey, Overview & Recommendations," for the Texas Sustainable Energy Development Council, July 1995, ISBN 0-9645526-0-4.

Weiz Institute of Science, "High-Concentration Solar Energy Optics," Sun Day Symposium.

Wene, C.O., 2000. Experience Curves for Energy Technology Policy. International Energy Agency, Paris, France. (ISBN 92-64-17650-0).

Wieckert, C., M. Epstein, G. Olalde, R. Palumbo, H. J. Pauling, H.-U. Reichardt, J.-F. Robert, S. Santen, and A. Steinfeld, 2002. "The SOLZINC-Project for Solar Carbothermic Production of Zn from ZnO," 11th SolarPACES International Symposium on Concentrated Solar Power and Chemical Energy Technologies, Zurich, Sep 4-6, 2002.

Williams, T., M. Bohn, and H. Price, 1995. "Solar Thermal Electric Hybridization Issues", Proceedings of the ASME/JSME/JSES International Solar Energy Conference, Maui, HI (March 19-24, 1995).

Winter, C. J., R. Sizmann, and L. Vant-Hull, eds., 1990. Solar Power Plants - Fundamentals, Technology, Systems, Economics. Springer-Verlag, Berlin, 1990, ISBN 3-540-18897-5.

World Bank, 1999. "Cost Reduction Study for Solar Thermal Power Plants." Prepared by Enermodal Engineering Limited in association with Marbek Resource Consultants Ltd. (11)

Yogev, A., A. Kribus, M. Epstein, A. Kogan, 1998. Solar "Tower Reflector" Systems: A New Approach for High-Temperature Solar Plants, Int. J. Hydrogen Energy, 23(4):239-245, 1998.

Zhang, Q., Zhao, K., Zang, B., Wang, L., Shen, A., Zhou, Z., Lu, D., Xie, D., and Li, B., 1998. ''New Cermet Solar Coatings for Solar Thermal Electricity Applications,'' Solar Energy.

ADDITIONAL INFORMATION SOURCES

This list contains supplementary documents reviewed in preparing information for the report. If available, the CSP Technology Review Information Index number is given in parenthesis following the item. These numbers also indicate that the document is included on the attached compact disk. Numbers above 70 are added to those items that did not have a CSP Technology Review Information Index number but are also included on the disk.

Arthur D. Little, Inc., 2001. “Review: Status of and Markets for Solar Thermal Power Systems,” Slide presentation to Sandia National Laboratories, Albuquerque, New Mexico, November 2001. (74)

Baldwin, S., 2002. “Peer Review of Future CSP Cost and Performance,” Memorandum to D. Garman, April 12, 2002. (01)

Blake, D. M., L. Moens, 2001. “Milestone 2.2.2b - Document Research on Ionic Fluids and Identify the Most Promising Approaches,” National Renewable Energy Laboratory, September 28, 2001. (Included with Mehos 2001)

Cohen, G. E., D. W. Kearney, G. J. Kolb, 1999. Final Report on the Operation and Maintenance Improvement Program for Concentrating Solar Power Plants,” SAND99-1290, Sandia National Laboratories, Printed June 1999. (24)

Committee on Programmatic Review of the U.S. Department of Energy’s Office of Power Technologies, 2000. *Renewable Power Pathways: A Review of the U.S. Department of Energy’s Renewable Energy Programs*, The National Academy of Sciences, National Academy Press, Washington D.C. (03)

CSP Peer Review Panel, 2001. “Concentrating Solar Power Peer Review Final Report,” Slide presentation, Albuquerque, New Mexico, November 7–9, 2001. (05.2)

CSP Peer Review Panel, eds. 2001. “Concentrating Solar Power Peer Review,” Presentations, Albuquerque, New Mexico, November 7–9, 2001. (05.3)

Dersch, J., M. Geyer, U. Hermann, S. A. Jones, B. Kelly, R. Kistner, W. Ortmanns, R. Pitz-Paal, H. Price, 2002. “Solar Trough Integration into Combined Cycle Systems,” Proceedings of Solar 2002, ASME, Sunrise on the Reliable Energy Economy, June 15–20, 2002, Reno, Nevada. (25.2)

Duke Solar Energy, Inc., 2002. “Subtask 1.1 Final Report: Parabolic Trough Space Frame Structural Analysis,” USA-Trough Initiative: Advanced Parabolic Trough System Design, NREL Subcontract No. NAA-1-30441-06, submitted to National Renewable Energy Laboratory May 7, 2002. (17)

Geyer, M., E. Lüpfert, R. Osuna, A. Esteban, W. Schiel, A. Schweitzer, E. Zarza, P. Nava, J. Langenkamp, and Eli Mandelberg, undated. “EUROTROUGH – Parabolic Trough Collector Family Developed and Qualified for Cost Efficient Solar Power Generation.” (72)

Harmon, C., 2000. “Experience Curves of Photovoltaic Technology,” Interim Report, International Institute for Applied Systems Analysis, IR-00-014, Laxenburg, Austria. (76)

Jones, S. 2002. “Power Tower Technology,” Slide presentation, NRC Kickoff Meeting, Washington, D.C. August 13, 2002. (79)

Kelly, B., 2000. *Lessons Learned, Project History, and Operating Experience of the Solar Two Project*, Nexant, LLC, SAND2000-2598, Sandia National Laboratories, Albuquerque, New Mexico, Printed November 2000.

Kelly, B., U. Herrmann [sic], M. J. Hale, 2001. “Optimization Studies for Integrated Solar Combined Cycle Systems,” Proceedings of Solar Forum 2001, ASME, Solar Energy: The Power to Choose, April 21–25, 2001, Washington, D.C. (25.1)

Kennedy, C. E., undated, “Review of Mid- to High Temperature Solar Selective Absorber Materials,” National Renewable Energy Laboratory, Golden, Colorado. (20.2)

KJC Operating Company, undated (2002). “SEGS Aquaintance [sic] & Data Package,” KJC Operating Company, SEGS III–VII (confidential).

KJC Operating Company, 2002. “Testing of Solel UVAC Trough Receiver Tubes,” Draft Contractor Progress Report, Task Order KAA-0-30448-01, May 31, 2002. (19.3)

Leitner, A., 2002. *Fuel from the Sky: Solar Power’s Potential for Western Energy Supply*, RDI Consulting, Platts, Boulder, Colorado, March 2002. (7.0)

Litwin, R. Z., 2002. “Receiver System: Lessons Learned from Solar Two,” The Boeing Company, SAND2002-0084, Sandia National Laboratories, printed March 2002. (41)

Luce, B., 2002. “Report on the Western Governor’s Association Solar Energy Meeting — January 18, 2002,” Desert Research Institute, Las Vegas, Nevada. (75)

Mahoney, R., 2000, “Trough Technology Heat Collector Element (HCE) Solar Selective Absorbers,” Sandia National Laboratories, Trough Workshop ASES 2000, June 18, 2000. (20.1)

Mahoney, R., 2001. “HCE Issues; Cermet Preliminary Results Optical Properties & Construction Forum 2001,” Slide presentation, Sandia National Laboratories, April 23, 2001. (19)

Mancini, T., G. Nakarado, G. Kolb, H. Price, M. Prairie, 1998. “Making a CSP Project Happen,” CSP Project Development Team, Project Thunderball Report, July 8, 1998. (09)

Mariyappan, J., and D. Anderson, 2002. “Thematic Review of GEF-Financed Solar Thermal Projects,” Monitoring and Evaluation Working Paper 7, Global Environment Facility, March 2002. (60)

Mehos, M., 2001. “Completion of Milestone 2.2.2b - Document Research on Ionic Fluids and Identify the Most Promising Approaches,” Memorandum to Tex Wilkins and Tom Rueckert, National Renewable Energy Laboratory, October 4, 2001. (23)

National Renewable Energy Laboratories, 2001. “CSP FY01 Milestone Report: Summary of Status of Most Promising Candidate Advanced Solar Mirrors (Testing and Development Activities),” slide presentation, September 30, 2001. (18)

Nexant Inc. 2000, “USA Trough Initiative: Thermal Storage Oil-to-Salt Heat Exchanger Design and Safety Analysis,” Task Order Authorization Number KAF-9-29765-09, San Francisco, California, November 30, 2000. (21)

Pacheco, J. E., S. K. Showalter, W. J. Kolb, 2001. “Development of a Molten-Salt Thermocline Thermal Storage System for Parabolic Trough Plants,” Proceedings of Solar Forum 2001, ASME, Solar Energy: The Power to Choose, April 21–25, 2001, Washington, D.C. (73)

Price, H., M. J. Hall, R. Forristall (National Renewable Energy Laboratory); R. Mahoney (Sandia National Laboratories); R. Fimbres, N. Potrovitza, C. Gummo (KJC Operating Company); and B. Cable (Duke Solar); 2002. “UVAC Preliminary Test Results,” Draft, May 2002. (19.1)

Price, H., 2002. “Trough Technology R&D Opportunities,” Slide presentation NAS briefing. (78)

Price, H., 2002. “Milestone Report for FY02 Milestone 2.1.4.a ‘Complete Assessment of Advanced Trough Receiver,’” Memorandum to M. Mehos, National Renewable Energy Laboratory, May 31, 2002. (19.2)

Price, H., V. Hassani, 2001. “Modular Trough Power Plants Cycle Analysis,” Technical Report, NREL/TP-550-31240, National Renewable Energy Laboratory, Golden, Colorado.

Romero, M., R. Buck, J. E. Pacheco, 2002. “An Update on Solar Central Receiver Systems, Projects, and Technologies,” *Journal of Solar Energy Engineering*, Transactions of the ASME, Vol. 124, May 2002. (38)

Spencer Management Associates, Inc. 2000. Final Report: Mexico Feasibility Study for an Integrated Solar Combined Cycle System (ISCCS), World Bank Contract 7107981, June 5, 2000. (28.1, 28.2)

Tester, J.W., 2001. “CSP Peer Review,” Memorandum to F. Wilkins, December 7, 2001. (05.1)

U.S. Concentrating Solar Power Industry Review Panel, 2000. “Rebuttal of the National Research Council’s Review of the U.S. DOE Concentrating Solar Power Program,” Executive Summary, June 2000. (3.1)

U.S. Department of Energy, 1998. “Concentrating Solar Power: Paths to the Future, Five-Year Program Plan 1998-2003,” Office of Solar Thermal, Biomass Power, and Hydrogen Technologies, U.S. Department of Energy, Washington D.C. April 1998. (77)

U.S. Department of Energy, 2002. “Strategic Program Review,” Energy Efficiency and Renewable Energy, U.S. DOE, March 2002. (4)

Williams, T., M. J. Hale, S. Schreck, H. Price, T. Wendelin, P. Cordeiro, 2002. “Concentrating Solar Power–Africa: Technology Screening,” NREL/TP-550-28558, National Renewable Energy Laboratory, Golden, Colorado, September 2000. (confidential)

Zavoico, A. B., 2001. *Solar Power Tower: Design Basis Document*, Revision 0, SAND2001-2100, Sandia National Laboratories, printed July 2001. (43)

SARGENT & LUNDY DOCUMENTS INCLUDED ON THE COMPACT DISK

Sargent & Lundy LLC, 2002. "Due Diligence of Parabolic Trough and Power Tower Solar Technology: Cost and Performance Forecasts," Slide presentation to National Research Council, August 12, 2002. (81)

Sargent & Lundy LLC, 2002. "Due Diligence of Parabolic Trough and Power Tower Solar Technology: Cost and Performance Forecasts," Slide presentation to National Research Council, September 30, 2002. (82)

Sargent & Lundy LLC, 2002. "Power Tower Technology," Slide presentation to National Research Council, September 30, 2002. (83)

Sargent & Lundy LLC, 2002. "Parabolic Trough Technology," Slide presentation to National Research Council, September 30, 2002. (84)

Sargent & Lundy LLC, 2002. "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts," Draft 3 Prepared for Department of Energy and National Renewable Energy Laboratory, October 2002. (85)

Sargent & Lundy LLC, 2003. "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts," Final Prepared for Department of Energy and National Renewable Energy Laboratory, May 2003. (86)

SUMMARY LIST OF ALL DOCUMENTS ON COMPACT DISK

Sargent & Lundy used a categorized, numerical system to track documents that might be used in the development of the report. Skipped numbers in the following list did not have documents associated with them or refer to confidential documents or to documents later found to be less pertinent than other, included, documents.

01 Baldwin, S., 2002. "Peer Review of Future CSP Cost and Performance," Memorandum to D. Garman, April 12, 2002.

03 Committee on Programmatic Review of the U.S. Department of Energy's Office of Power Technologies, 2000. *Renewable Power Pathways: A Review of the U.S. Department of Energy's Renewable Energy Programs*, The National Academy of Sciences, National Academy Press, Washington D.C.

03.1 U.S. Concentrating Solar Power Industry Review Panel, 2000. "Rebuttal of the National Research Council's Review of the U.S. DOE Concentrating Solar Power Program," Executive Summary, June 2000.

04 U.S. Department of Energy, 2002. "Strategic Program Review," Energy Efficiency and Renewable Energy, U.S. DOE, March 2002.

05.1 Tester, J.W., 2001. "CSP Peer Review," Memorandum to F. Wilkins, December 7, 2001.

05.2 CSP Peer Review Panel, 2001. "Concentrating Solar Power Peer Review Final Report," Slide presentation, Albuquerque, New Mexico, November 7–9, 2001.

05.3 CSP Peer Review Panel, eds. 2001. "Concentrating Solar Power Peer Review," Presentations, Albuquerque, New Mexico, November 7–9, 2001.

06 EERE, 2002. "Feasibility of 1,000 Megawatts of Solar Power in the Southwest by 2006."

07 Leitner, A., 2002. *Fuel from the Sky: Solar Power's Potential for Western Energy Supply*, RDI Consulting, Platts, Boulder, Colorado, March 2002.

09 Mancini, T., G. Nakarado, G. Kolb, H. Price, M. Prairie, 1998. "Making a CSP Project Happen," CSP Project Development Team, Project Thunderball Report, July 8, 1998.

10 Lotker, M., 1991. "Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the LUZ Experience," Sandia National Laboratories, Albuquerque, New Mexico: Report SAND91-7014.

11 World Bank, 1999. "Cost Reduction Study for Solar Thermal Power Plants." Prepared by Enermodal Engineering Limited in association with Marbek Resource Consultants Ltd.

13 Price, H., E. Lüpfert, D. Kearney, E. Zarza, G. Cohen, R. Gee, and R. Mahoney, 2002. "Advances in Parabolic Trough Solar Power Technology," Journal of Solar Energy Engineering, May 2002.

14 Price, H., and Kearney, D., 1999. "Parabolic-Trough Technology Roadmap: A Pathway for Sustained Commercial Development and Deployment of Parabolic-Trough Technology," NREL/TP-550-24748, NREL, Golden, Colorado.

16 Gee, R., G. Cohen, and R. Winston, 2002. "A Non-Imaging Receiver for Parabolic Trough Concentrating Collectors," Proceedings of Solar 2002.

17 Duke Solar Energy, Inc., 2002. "Subtask 1.1 Final Report: Parabolic Trough Space Frame Structural Analysis," USA-Trough Initiative: Advanced Parabolic Trough System Design, NREL Subcontract No. NAA-1-30441-06, submitted to National Renewable Energy Laboratory May 7, 2002.

18 National Renewable Energy Laboratories, 2001. "CSP FY01 Milestone Report: Summary of Status of Most Promising Candidate Advanced Solar Mirrors (Testing and Development Activities)," slide presentation, September 30, 2001.

19 Mahoney, R., 2001. "HCE Issues; Cermet Preliminary Results Optical Properties & Construction Forum 2001," Slide presentation, Sandia National Laboratories, April 23, 2001.

19.1 Price, H., M. J. Hall, R. Forristall (National Renewable Energy Laboratory); R. Mahoney (Sandia National Laboratories); R. Fimbres, N. Potrovitza, C. Gummo (KJC Operating Company); and B. Cable (Duke Solar); 2002. "UVAC Preliminary Test Results," Draft, May 2002.

19.2 Price, H., 2002. “Milestone Report for FY02 Milestone 2.1.4.a ‘Complete Assessment of Advanced Trough Receiver,’” Memorandum to M. Mehos, National Renewable Energy Laboratory, May 31, 2002.

19.3 KJC Operating Company, 2002. “Testing of Solel UVAC Trough Receiver Tubes,” Draft Contractor Progress Report, Task Order KAA-0-30448-01, May 31, 2002.

20.1 Mahoney, R., 2000, “Trough Technology Heat Collector Element (HCE) Solar Selective Absorbers,” Sandia National Laboratories, Trough Workshop ASES 2000, June 18, 2000.

20.2 Kennedy, C. E., undated, “Review of Mid- to High Temperature Solar Selective Absorber Materials,” National Renewable Energy Laboratory, Golden, Colorado.

21 Nexant Inc. 2000, “USA Trough Initiative: Thermal Storage Oil-to-Salt Heat Exchanger Design and Safety Analysis,” Task Order Authorization Number KAF-9-29765-09, San Francisco, California, November 30, 2000.

22.1 Kearney, D., 2001a. Engineering Evaluation of a Molten Salt HTF in a Parabolic Trough Solar Field, Task 6 Report, Final System Performance and Cost Comparisons, August 20, 2001.

22.2 Kearney, D., 2001b. “Engineering Evaluation of a Molten Salt HTF in a Parabolic Trough Solar Field,” Task 7 Report, Recommendations on Development Needs, September 15, 2001.

23 Blake, D. M., L. Moens, 2001. “Milestone 2.2.2b - Document Research on Ionic Fluids and Identify the Most Promising Approaches,” National Renewable Energy Laboratory, September 28, 2001. (Included with Mehos 2001)

23 Mehos, M., 2001. “Completion of Milestone 2.2.2b - Document Research on Ionic Fluids and Identify the Most Promising Approaches,” Memorandum to Tex Wilkins and Tom Rueckert, National Renewable Energy Laboratory, October 4, 2001.

24 Cohen, G. E., D. W. Kearney, G. J. Kolb, 1999. Final Report on the Operation and Maintenance Improvement Program for Concentrating Solar Power Plants,” SAND99-1290, Sandia National Laboratories, Printed June 1999.

25.1 Kelly, B., U. Herrmann [sic], M. J. Hale, 2001. "Optimization Studies for Integrated Solar Combined Cycle Systems," Proceedings of Solar Forum 2001, ASME, Solar Energy: The Power to Choose, April 21–25, 2001, Washington, D.C.

25.2 Dersch, J., M. Geyer, U. Hermann, S. A. Jones, B. Kelly, R. Kistner, W. Ortmanns, R. Pitz-Paal, H. Price, 2002. "Solar Trough Integration into Combined Cycle Systems," Proceedings of Solar 2002, ASME, Sunrise on the Reliable Energy Economy, June 15–20, 2002, Reno, Nevada.

28.1 Spencer Management Associates, Inc. 2000. Final Report: Mexico Feasibility Study for an Integrated
28.2 Solar Combined Cycle System (ISCCS), World Bank Contract 7107981, June 5, 2000.

38 Romero, M., R. Buck, J. E. Pacheco, 2002. "An Update on Solar Central Receiver Systems, Projects, and Technologies," *Journal of Solar Energy Engineering*, Transactions of the ASME, Vol. 124, May 2002.

39 Reilly, H.E., and G.J. Kolb, 2001. "An Evaluation of Molten-Salt Power Towers Including the Results of the Solar Two Project," SAND2001-3674, Sandia National Laboratories.

40 Pacheco, J.E. (ed), G.J. Kolb, H.E. Reilly, S.K. Showalter, S.H. Goods, R.W. Bradshaw, D.B. Dawson, S.A. Jones, M.J. Hale, R.L. Gilbert, M.R. Prairie, and P. Jacobs, 2002. "Final Test and Evaluation Results from the Solar Two Project," SAND2002-0120, Sandia National Laboratories, Albuquerque, NM.

41 Litwin, R. Z., 2002. "Receiver System: Lessons Learned from Solar Two," The Boeing Company, SAND2002-0084, Sandia National Laboratories, printed March 2002.

43 Zavoico, A. B., 2001. *Solar Power Tower: Design Basis Document*, Revision 0, SAND2001-2100, Sandia National Laboratories, printed July 2001.

60 Mariyappan, J., and D. Anderson, 2002. "Thematic Review of GEF-Financed Solar Thermal Projects," Monitoring and Evaluation Working Paper 7, Global Environment Facility, March 2002.

70 Neij, Lena, 1997. "Use of Experience Curves to Analyse the Prospects for Diffusion and Adoption of Renewable Energy Technology," *Energy Policy*, Vol. 23, No. 13, pp. 1099-1107, 1997.

71 Morse, Frederick H., 2000. "The Commercial Path Forward for Concentrating Solar Power Technologies: A Review of Existing Treatments of Current and Future Markets," Morse Associates, Inc., Washington D.C., December 13, 2000.

72 Geyer, M., E. Lüpfert, R. Osuna, A. Esteban, W. Schiel, A. Schweitzer, E. Zarza, P. Nava, J. Langenkamp, and Eli Mandelberg, undated. "EUROTROUGH – Parabolic Trough Collector Family Developed and Qualified for Cost Efficient Solar Power Generation."

73 Pacheco, J. E., S. K. Showalter, W. J. Kolb, 2001. "Development of a Molten-Salt Thermocline Thermal Storage System for Parabolic Trough Plants," Proceedings of Solar Forum 2001, ASME, Solar Energy: The Power to Choose, April 21–25, 2001, Washington, D.C.

74 Arthur D. Little, Inc., 2001. "Review: Status of and Markets for Solar Thermal Power Systems," Slide presentation to Sandia National Laboratories, Albuquerque, New Mexico, November 2001.

75 Luce, B., 2002. "Report on the Western Governor's Association Solar Energy Meeting — January 18, 2002," Desert Research Institute, Las Vegas, Nevada.

76 Harmon, C., 2000. "Experience Curves of Photovoltaic Technology," Interim Report, International Institute for Applied Systems Analysis, IR-00-014, Laxenburg, Austria.

77 U.S. Department of Energy, 1998. "Concentrating Solar Power: Paths to the Future, Five-Year Program Plan 1998-2003," Office of Solar Thermal, Biomass Power, and Hydrogen Technologies, U.S. Department of Energy, Washington D.C. April 1998.

78 Price, H., 2002. "Trough Technology R&D Opportunities," Slide presentation NAS briefing.

79 Jones, S. 2002. "Power Tower Technology," Slide presentation, NRC Kickoff Meeting, Washington, D.C. August 13, 2002.

80 National Research Council (NRC) Committee for the Review of a Technology Assessment of Solar Power Energy Systems, 2002. "Critique of the Sargent & Lundy Assessment of Cost and Performance Forecasts for Concentrating Solar Power," October 12, 2002 [Note the review was performed on Draft 3 of the Sargent & Lundy Report, SL-5641, dated October 2002]

81 Sargent & Lundy LLC, 2002. "Due Diligence of Parabolic Trough and Power Tower Solar Technology: Cost and Performance Forecasts," Slide presentation to National Research Council, August 12, 2002.

82 Sargent & Lundy LLC, 2002. "Due Diligence of Parabolic Trough and Power Tower Solar Technology: Cost and Performance Forecasts," Slide presentation to National Research Council, September 30, 2002.

83 Sargent & Lundy LLC, 2002. "Power Tower Technology," Slide presentation to National Research Council, September 30, 2002.

84 Sargent & Lundy LLC, 2002. "Parabolic Trough Technology," Slide presentation to National Research Council, September 30, 2002.

85 Sargent & Lundy LLC, 2002. "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts," Draft 3 Prepared for Department of Energy and National Renewable Energy Laboratory, October 2002.

86 Sargent & Lundy LLC, 2003. "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts," Final Prepared for Department of Energy and National Renewable Energy Laboratory, May 2003.

87 Arthur D. Little, Inc., 2001. "Heliostat Cost Review," June 2001.

88 Peerless-Winsmith, Inc., 1996. "Results of Dual Axis Solar Drive DFMA Workshop," Contract ACG-5-15209-01, January 26, 1996.

89 Peerless-Winsmith, Inc., 1999. "Enhanced Azimuth Solar Drive Project Summary Report," for Sandia National Laboratories, Contract Number BF-0031, October 1999.

90 Science Applications International Corporation, 1996. "Heliostat Cost Study for SOLMAT Program," for National Renewable Energy Laboratory, Golden, CO.

91 Solar Kinetics, Inc., 1996. SolMatT, Mirror Module Assembly Plan and Cost Estimate.

92 Teagan, W. Peter, 2001. "Review: Status of Markets for Solar Thermal Power Systems," Arthur D. Little, Sandia Report SAND2001-2521P, May 2001.

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 2003	3. REPORT TYPE AND DATES COVERED Subcontract Report

4. TITLE AND SUBTITLE Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts, Executive Summary	5. FUNDING NUMBERS CP032000 LAA-2-32458-01
6. AUTHOR(S) Sargent & Lundy LLC Consulting Group	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Sargent & Lundy LLC Consulting Group 55 East Monroe Street Chicago, IL 60603-5780	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	10. SPONSORING/MONITORING AGENCY REPORT NUMBER NREL/SR-550-35060

11. SUPPLEMENTARY NOTES
NREL Technical Monitor: Henry Price

12a. DISTRIBUTION/AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Sargent & Lundy LLC conducted an independent analysis of parabolic trough and power tower solar technology cost and performance.

14. SUBJECT TERMS parabolic trough; power tower; solar; solar technology; concentrating solar power; CSP; power generation	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102