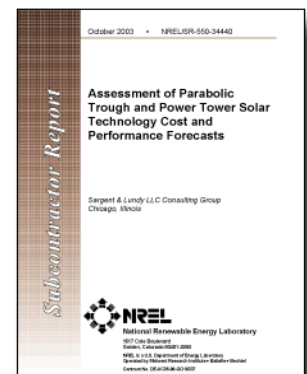


Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts

*Sargent & Lundy LLC Consulting Group
Chicago, Illinois*



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

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NREL Technical Monitor: H. Price

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



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

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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

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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

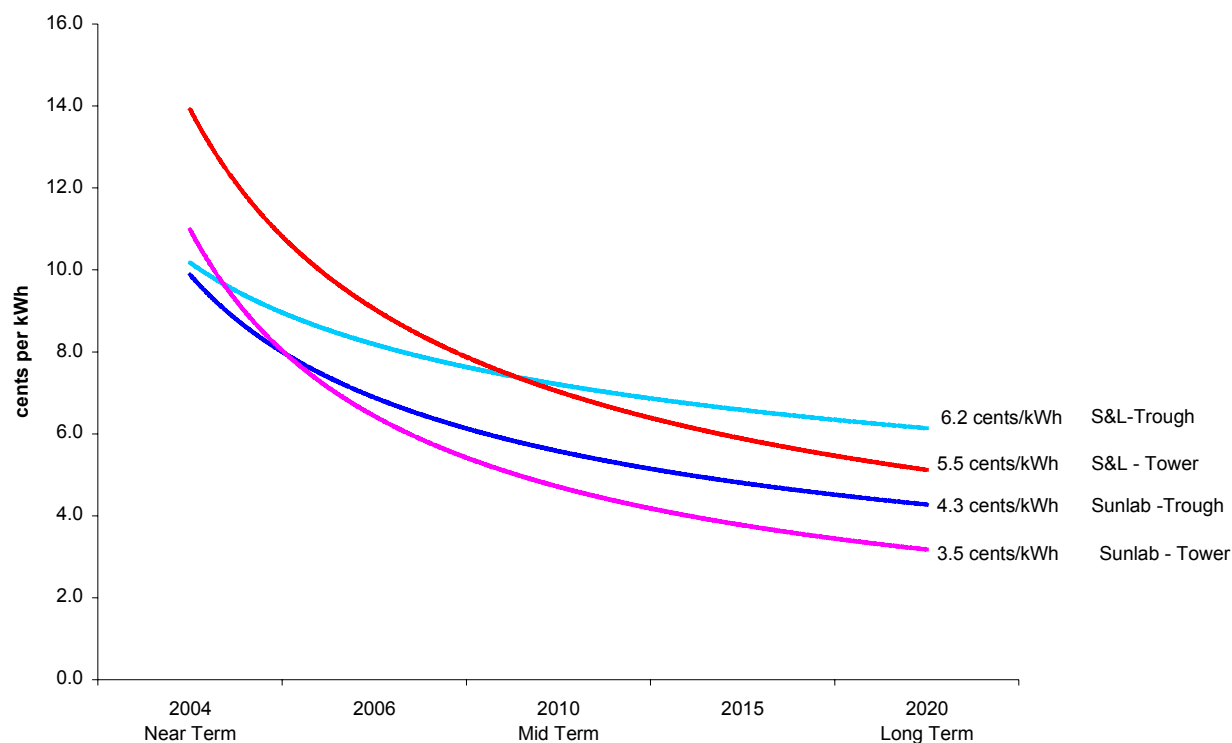
improvements are limited to current demonstrated or tested improvements and with a relatively low rate of deployment (this does not mean that there is no technology development, only that the technologies have been demonstrated or tested at some scale so that no breakthroughs are required; further scale-up 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 achieved.

Trough Technology S&L Base Case

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

	<u>Trough</u>
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 m³). SunLab estimated the cost to be \$0.021 per m³, 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 m³). SunLab estimated the cost to be \$0.021 per m³, 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 m² heliostats from \$148/m² to \$94/m².

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 deliberate 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 rationale 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 parentheses are included on the attached compact disk, keyed to that number.

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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.

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REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188
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