THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Board on Energy and Environmental Systems
Division on Engineering Physical Sciences

NOV 22 2002

The Honorable David K. Garman
Assistant Secretary for Energy Efficiency and Renewable
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

Dear Assistant Secretary Garman:

I am pleased to provide you with a copy of the letter report, "Critique of the Sargent and Lundy Assessment of Cost and Performance Forecasts for Concentrating Solar Power Technology" which has been prepared by a committee operating under the aegis of the Board on Energy and Environmental Systems.

On behalf of the committee, I want to thank the members of your staff who provided substantial information and briefings for use in the study. The committee, in addition, found Sargent & Lundy highly responsive to the demands of interacting with the committee and providing updated drafts of their assessment. The committee also benefited from informative briefings by SunLab, the solar power industry and the broader community.

Please feel free to contact Martin Offutt, Responsible Staff Officer for the study at 202-334-2904, or James Zucchetto, Director, Board on Energy and Environmental Systems, at 202-334-3222 if you would like more information on this or any other Board on Energy and Environmental Systems activity. If you would like to discuss the committee's report, please feel free to call me at 608-263-1601.

Sincerely,

Gerald L. Kulcinski
Committee Chairman

cc: Sam Baldwin
Frank Wilkins
Tommy Rueckert

Critique of the Sargent & Lundy Assessment of Cost and Performance Forecasts for Concentrating Solar Power

This letter report is the result of a brief but intensive study by the National Research Council (NRC) Committee for the Review of a Technology Assessment of Solar Power Energy Systems. Prepared for the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EE&RE), this report critiques an assessment by Sargent & Lundy LLC (S&L), also contracted by the DOE, of the cost and performance forecasts for parabolic trough and power tower concentrating solar power (CSP) technology.[1] The NRC committee reviewed several drafts of the S&L document; however, this letter report is based mainly on Draft 3, which was delivered to the committee on October 12, 2002 [1]. The Executive Summary of that draft (SL-5641) is reproduced in Appendix A. Several post-October 12 revisions sent to the committee are also included in this analysis.[2]

The committee's statement of task was as follows:

> The National Research Council will establish a committee that will review an analysis of the technical opportunities to reduce the cost of generating electricity using concentrating solar power (CSP) technologies out to 2020, the reasonableness of the assumptions for achieving these estimated costs, and the key technical challenges in achieving them. This analysis will be conducted by an independent contractor that will conduct a "due diligence-like" analysis, incorporating the latest data available on CSP technologies. The committee will review the contractor's analysis and write a letter report commenting, as

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[1] This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Donald Brand, NAE, Pacific Gas and Electric Company, retired; Charles Goodman, Southern Company Services, Inc.; H.M. Hubbard, Pacific International Center for High Technology Research, retired; Frank Incropera, NAE, University of Notre Dame; Terry Peterson, Electric Power Research Institute; and T.G. Theofanous, NAE, University of California, Santa Barbara.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by David Bodde, University of Missouri. Appointed by the National Research Council, he was responsible for making sure that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

[2] S&L made revisions to the Executive Summary, Introduction, Glossary, and its assessment of the impact of tax credits and accelerated cost recovery on the levelized cost of energy (LEC).

> needed, on the assumptions, quality, strengths, weaknesses, objectivity, and credibility of the analysis. The committee's analysis will include consideration of multiple technology pathways, potential technology advances to 2020, and the possible benefits accruing from economies of scale and learning under various scenarios of manufacturing scale up and large-scale deployment.

Because its task was narrowly focused, the committee emphasizes that numerous factors significantly influencing the future of CSP were outside the scope of review. Accordingly, the committee's report:

- Does not take a position on the desirability of DOE support of CSP;
- Does not consider the economic competitiveness of CSP alone or within a portfolio of renewable energy options;
- Does not consider economic competitiveness against fossil or nuclear energy;
- Does not develop independent estimates of cost projections;
- Does not incorporate environmental externalities (e.g., carbon credits);
- Does not discuss policy-based incentives such as energy taxes or credits (other than investment tax credit (ITC) and accelerated depreciation as assumed by S&L), renewable portfolio standards,[3] or other fiscal and energy policy at the federal and state level;
- Does not express an independent judgment of previous NRC or other studies and reviews of the economics, technology, and programmatic status of CSP;
- Does not comment on the DOE's future programmatic strategy for the development of CSP.

To conduct its review, the NRC appointed a 10-member committee (see Appendix B) that first met on August 12 through 14, 2002, to review the S&L work with the aim of having a "fast track" report completed by mid-November 2002. The NRC committee met twice (see Appendix C) and several members of the committee also conducted a site visit to the Kramer Junction facility on August 29, 2002. The remainder of this report comprises six sections. The first describes the context for the committee's efforts. The next two evaluate S&L's assessment of the potential to lower the costs of CSP troughs and towers in the United States. The fourth section then focuses on S&L's deployment forecast, a topic that the committee addressed early in its study and revisited frequently during its reading of several S&L draft reports. The committee regards these forecasts as a dominant issue in any assessment of the potential for realizing projected cost reductions.

[3] A renewable portfolio standard is a requirement that a certain percentage of an electric utility's energy be generated by using renewable resources—energy from the sun (solar), wind, flowing water (hydropower), earth heat (geothermal), or organic materials (biomass, including agricultural and municipal waste materials).

The fifth section presents additional comments on the S&L analysis. The last section contains the committee's findings and recommendations. In the course of the review, the committee developed several important observations and suggestions that, although outside the narrow scope of the original charge, it considers as important as the conclusions directly addressing the charge. A summary of these additional comments, along with additional findings and recommendations of the committee, can be found in Appendix D.

CONTEXT

In 1997, the President's Committee of Advisors on Science and Technology (PCAST) [2] foresaw the potential of renewable energy technologies, including CSP technologies, to reduce greenhouse gas emissions, dependent on further technical progress and cost reductions, and their ability to compete with other means of generating electricity. In 1999-2000, the NRC's Committee on Programmatic Review of the U.S. Department of Energy's Office of Power Technologies (OPT) (at that time OPT was part of the DOE's EE&RE office) reviewed DOE's effort to develop clean, renewable, and cost-effective sources of electricity [3] . That study considered all three of DOE's technical approaches to CSP: [4]

1. Trough systems, in which solar energy is concentrated by a field of parabolically curved, trough-shaped reflectors onto a receiver pipe running along the inside of the curved surface;
2. Power-tower systems in which sunlight is concentrated by a field of mirrors (heliostats) onto a receiver at the top of a tower, heating a working fluid to produce steam for an electric generator; and
3. Dish/engine systems in which sunlight is collected and concentrated by a dish-shaped surface onto a receiver that absorbs the energy and transfers it to an engine's working fluid.

The 2000 report found overall that the commercial prospects for CSP technologies and privately funded projects were not very promising [3]. Specifically, it concluded that "the Office of Power Technologies should limit or halt its research and development on power-tower and power-trough technologies because further refinements would not lead to deployment" (p. 65). The report also recommended that the market prospects for solar dish/engine technologies should be reassessed to determine whether additional R&D was warranted.

According to the 2000 report, DOE stated that the cost of power-trough technology was about 11-12 cents/kWh, although industry analysts suggested it was higher, at 16 cents/kWh [3]. DOE projected that costs would reach 8 cents/kWh by 2003 or 2004 [3]. The NRC's 2000 report also expressed the opinion that foreign markets would be more likely for CSP technologies, although significant incentives by a financial institution

[4] There are also approaches to concentrating sunlight on photovoltaic devices to convert sunlight directly into electricity.

would probably be required. The implementation of renewable portfolio standards in the United States, either at the federal or state levels, could change the market for these technologies as well.

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. Although no CSP projects are currently under construction, as noted in the S&L report evaluated by the committee, technical progress has resulted in reductions of operation and maintenance (O&M) costs in recent years for working trough systems deployed in California. The longer-term potential (out to 2020) of such advances for troughs and towers is the specific focus of the S&L report.

During the past 2 years, DOE and industry, frequently in collaboration, have generated additional data, information, and analyses on the characteristics, performance, and economics of CSP technologies and on technical developments that could lead to improved performance and reduced cost. In light of recent information and the latest data on CSP technologies, EE&RE charged S&L to conduct a "due diligence-like" analysis of the technical opportunities for reducing cost, to examine the likelihood of achieving estimated costs of producing electricity, and to identify the key challenges to achieving success. The DOE asked the NRC to conduct a review of this analysis and comment on its assumptions, quality, accuracy, strengths, weaknesses, objectivity and credibility, as appropriate (see statement of task).

EVALUATION OF SARGENT & LUNDY ASSESSMENT OF POTENTIAL FOR COST REDUCTION—TROUGHS

Sargent & Lundy's report [1] reviews trough technology from the standpoint of what has been achieved in the past 20 years of development and deployment as well as in terms of the projections of improved performance and lower component costs in a path forward.

The committee recognized that S&L's modeling approach parallels SunLab's[5] in almost all aspects. S&L also reviewed other available economic estimates of trough technology from European and U.S. industrial and government sources. In general, S&L assumes a slightly lower level of performance for components than does SunLab (e.g., S&L [1] Table 4.3). Component costs are generally higher in S&L's estimate compared to SunLab's for the mid and long-term periods—the main exception being the power block. As a result, S&L's capital costs are higher than SunLab's: for example, in 2020, S&L projects $3,220/kW versus $2,225/kW from SunLab.

[5] The U.S. Department of Energy (DOE) administers the Concentrating Solar Power Program through two of its national laboratories: Sandia National Laboratories in Albuquerque, New Mexico, and the National Renewable Energy Laboratory in Golden, Colorado. To increase the administrative efficiency of the program and leverage the respective technical expertise of each of the laboratories, the concentrating solar power departments of each laboratory have been combined into a single business unit called SunLab.

The S&L report correctly states that CSP trough technology has been demonstrated at commercially relevant sizes up to 80 MW_e [1]. A total of 354 MW_e has been installed and has been operating at the Kramer Junction Solar Electric Generating Station (SEGS) site for over a decade. Given this history, there is little doubt that trough technology could be deployed in high-grade areas such as the U.S. Southwest and that it could be counted on to generate electricity reliably for a sustained period. Key issues are capital cost and dispatchability. If the trough plants were designed to be solar-only and fully dispatchable, additional capital investment would be required for the thermal storage systems and expanded solar fields. If they were designed as hybrids with natural gas co-firing, the capital investment would be somewhat less, but there would be a dollars per kilowatt hour cost associated with the use of natural gas. Systems without storage would have lower capital costs in dollars per kilowatt but their lower capacity factors would increase generation costs expressed in terms of a breakeven or levelized energy cost (LEC) in dollars per kilowatt hour.

The SunLab deployment scenarios evaluated by S&L represent a range from a modest rate of adding one 100-MW_e plant per year (the first becoming operational in 2004) to an aggressive approach that would result in almost 5,000 MW_e of new capacity by 2020. What path is actually taken will depend primarily on policy and economic development issues rather than technology developments. Technology improvement is certainly necessary to enhance the economic competitiveness and reduce the risks of trough technology. However, technology improvements alone are not sufficient to make CSP systems economically competitive (see section below, "Evaluation of Sargent & Lundy Deployment Forecast").

S&L carefully reviewed the O&M rate structure and components used by SunLab. Additional input based on evolving data from the Kramer Junction site was also used in S&L's review [1]. Replacement of common mode components and cleaning of reflector surfaces are critical issues. By and large, S&L used higher replacement rates than did SunLab. The committee believes that S&L estimates in this area are appropriately conservative and improve on SunLab's estimates of O&M costs. On average, S&L's estimates of O&M costs, ranging from 3.8 cents/kWh in the near term to 2.1 cents/kWh in the long term, are 65 to 100 percent higher than SunLab's.

The S&L estimates of capital costs and LEC for trough-produced electricity are also higher than SunLab's estimates under a comparable set of economic assumptions. The S&L study uses a set of economic assumptions similar to those used by SunLab in terms of debt/equity ratio, interest on debt, debt service coverage ratio, internal rate of return, interest and tax rates, and currently allowed tax credits and accelerated depreciation. While S&L's selection of base case economic parameters seems reasonable, its review did not sufficiently examine the effect of uncertainties on these parameters. As discussed in the section on deployment below, S&L conducted a limited amount of parameter sensitivity analysis of LECs at the committee's request.

S&L has projected that troughs will produce electricity in the near term (2004) at about 10.4 cents/kWh and that this rate will decrease to 6.2 cents/kWh in the long term (2020).

The SunLab predictions were 9.9 cents/kWh, decreasing to 4.3 cents/kWh over the same time period. According to S&L's analysis of the SunLab scenario, the total reduction in costs is a result of three factors: volume production (26 percent), plant scale up (20 percent) and technology advances (54 percent). For the S&L scenario, cost reductions come from volume production and plant scale-up alone, as S&L took the conservative position that few technical advances in trough technology would be made beyond 2004.

S&L also points out that if a robust, aggressive R&D program is supported and proves successful, and if policy measures are in place to facilitate deployment, then even lower costs of 4 cents/kWh may even be possible [1]. But the committee saw in S&L's report no convincing evidence to support that conclusion. 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.

The committee agrees with S&L's identification of key technology components for increasing the performance of trough systems to lower costs. These components, which need to be addressed by U.S. and international industries, are as follows:

1. Improved heat collector elements (HCEs)—for example, better metal-to-glass seals that are more resistant to thermal stress failure, the development of high-absorptivity low-emissivity coatings, and the selection of more stable heat transfer fluids.
2. Improved mirror/reflector designs—reflectors/mirrors with thinner glass to reduce losses and that use non-metallic reflectors, as well as lower maintenance, and improved durability as design objectives.
3. Reduced parasitic pumping losses and maintenance requirements for the piping in the collector field through development of improved connections between modules.
4. Affordable and workable direct thermocline thermal storage at temperatures up to 450^{o}C operable for 12-hr periods.
5. Improved lightweight mirror support structures that can maintain accurate alignment of the line focus over long time periods and under a variety of weather conditions, thus avoiding burnout of the HCEs.

The committee notes that S&L is cautious about increasing operating temperatures to 500^{o}C even though there would be improved efficiencies as a result. S&L did examine the effect of storage temperature on costs and showed that going to 500^{o}C had a small effect on LEC compared to storage at 450^{o}C.

In addition, S&L projects that cost reductions will result from increased production of new concentrator structures, improved reflectors, and receivers/absorbers that will increase capture efficiency and reliability as well as streamline manufacturing methods for these modular components. Modest improvements in O&M costs as more experience is gained are also estimated by S&L.

The extensive experience with electric power generation at S&L leads to high confidence among the committee in its estimates for power block cost reductions that will result from increasing plant size from, say, 100 to 400 MW_e.

The committee agrees with S&L that these are the key technology and production volume issues for troughs. What is difficult to assess at this point is whether the energy policies and significant financial incentives will be implemented to provide the necessary market pull to move CSP deployment forward. Furthermore, as the U.S. DOE/EE&RE concludes in its August 2002 report to Congress [4], it is questionable whether, under the current development programs in U.S. industry, there will be sufficient R&D resources to support the levels and rates of technology development needed to achieve the improved efficiencies for troughs.

EVALUATION OF SARGENT & LUNDY ASSESSMENT OF POTENTIAL FOR COST REDUCTION— TOWERS

Sargent & Lundy has performed a review of the power plant characteristics from the baseline Solar II and the near-term Solar Tres to the longer-term Solar 50, 100, 200, and 220 plants. The biggest difference in performance is between the Solar II and Solar Tres due to the addition of 16-hr storage and an expanded field size to enable a significant increase in capacity factor from 21 percent to 78 percent and deployment of new receiver panels tested briefly at Solar II.

Although Solar II represents an excellent pilot-plant demonstration, it is probably premature to consider its operation as a testament to commercial readiness. The committee notes that S&L has acknowledged this fact, and S&L concludes in the executive summary section that to achieve the cost reductions of scale-up, a total redesign and optimization of the field, the tower, and receiver are required. This implies considerable engineering development by commercial developers with commensurate risk to investors.

In this section, the design improvements listed for each of the tower system components suggests a full spectrum of engineering to advanced R&D activities. The committee notes that such improvements would require a significantly enhanced technology development program, much beyond what has been or is being invested in by industry or the government over the past decade.

Tower Efficiency. The committee believes that S&L has reasonably assessed the improvements in annual tower efficiency of the power plant progression, Solar Tres through Solar 220, although the advanced technology improvements of various components are by no means certain.

Evaluation of Major Cost Components. The heliostats, the receiver, and the power block account for 74 percent of the tower costs. It is appropriate that S&L focused its review primarily on these components, although the impacts of thermal storage, balance of plant, tower and piping, structures and improvements, etc., on the overall system design were not sufficiently addressed. The reason this is important is that to achieve the stated cost reductions, a total redesign and optimization of the field, tower, and receiver are required and have been incorporated for designs beyond Solar Tres.

S&L appears to have done a reasonable job of assessing the design and capital cost potential for systems based on near-term (or demonstrated) technologies. It then appears to accept the risks and uncertainty in advanced systems and shows major capital cost and LEC improvements with little discussion as to the viability of these technology advances. The discussion of risks and uncertainty is extremely shallow. Although a claim is made for a 10 percent contingency, this is not much more than the contingency factor that would be placed on a conventional plant design when it is in the "pre-preliminary" design state—which is where S&L's analysis of CSP plants now stands. To go beyond this very preliminary cost estimate would require a bottom-up, design sized equipment list, materials break out, and cost analysis at a specific site, and this effort was not within S&L's work scope.

Heliostats. An Arthur D. Little (ADL) study was used as a starting point in much of S&L's cost analysis. ADL is neither a manufacturer nor a constructor. S&L appears to have accepted ADL's analysis without much question and has not commented on the viability of ADL's vendor estimates. S&L asserts that it is basing costs on its internal experience and industrial experience, but since it is not an expert in CSP technology, it is not clear where S&L's estimates come from.

Much of the heliostat cost reduction hinges on the scale-up of heliostats from 95 m^2 to 148 m^2. S&L has not commented on the viability of this scale-up, especially as it relates to implications for failure modes, such as could occur due to increased wind loads and loss of structural integrity in micro-storms, etc.

Technology improvements reviewed by S&L include thinner glass for improved reflectivity and lower cost, improved aiming, better maintenance practices, and ultimately an enhanced heliostat for Solar 220. These seem to be assumptions without much to back up how such improvements will be accomplished.

Electrical Power Block. The primary cost reductions for the power block come from the scale-up. S&L has used its SOAPP (State of the Art Power Plant) model developed for the Electric Power Research Institute (EPRI) in its assessment of costs and has estimated a lower cost for the power block than SunLab's projections. For the conventional technology this seems reasonable. However, for the projected technology improvement of the steam turbine in the Solar 220 plant there appear to be some issues. Steam turbine technology has been at approximately 540°C steam inlet conditions for 50 years. It is unlikely that it will go to 640°C in the next 18 years. Also, 640°C with double reheat conditions might occur in large units (i.e., >400 MW) but not at smaller sizes. Furthermore, it is not clear that S&L really determined efficiency levels from the General Electric Company (GE) data system for the small-size plants it is considering (steam turbine cycle efficiency is very size dependent).

Receiver. The S&L review [1] of the SunLab and Boeing cost reduction projections defers to the engineering expertise of Boeing to guide cost estimates. The committee notes that initially, from Solar Tres to Solar 50 plants, cost reductions are primarily due to scale-up. Still, as is especially true of Solar 100 and 200 plants, there are significant cost reductions due to technical advances in selective coatings (increased absorptivity and decreased emissivity) and smaller-surface high-nickel tubes. It is anticipated that industry R&D will deliver the technical advances appropriate for the receivers.

S&L makes no comment about the severe technical risks in developing high-temperature and high-heat-flux systems for the future. It accepts as fact that these technology problems will be overcome. A simple thing like thermal transients at the heat flux, temperature, and size levels could be a real showstopper. There is no clear-cut technology path to success for these advanced systems, which will require two to five parallel technology breakthroughs. However, S&L projects LEC for its "conservative" deployments as if that LEC is achievable in 18 years, with little or no comment about the risk factors.

Thermal Storage. The cost reductions related to the thermal storage system are primarily due to scale-up. It appears that S&L has adequately assessed these cost reductions. On the technology development side, it is noted that for the advanced steam turbine, the projections have assumed a 640°C turbine inlet for added efficiency without much discussion of the heat transfer fluid and thermal storage development that would be required. It is a general concern of the committee's that advantages were assumed without significant consideration of all the side issues that might result with molten salts, e.g., pumps, seals, and pipes at temperature levels of >500°C.

Balance of Plant. The balance of plant (BOP) review by S&L was measured against its database and suggested a significantly higher cost estimate for BOP than SunLab's estimate. This is a good start.

Operation and Maintenance. The S&L review of O&M cost projections appears to have adequately assessed SunLab's estimates based on operational experience with troughs. S&L's small revisions seem appropriate. However, there should be more comment about O&M practices and the differences between towers and troughs.

Levelized Energy Cost. S&L has conducted an assessment of LEC calculations within the capital cost reductions that are projected through an assumed deployment rate. It is noted that S&L's calculation of LEC is very close to that of SunLab. Additionally, assigning uncertainty factors to technology improvements, scale-up, and volume production leads to approximately 25 percent uncertainty in the final long-term LEC calculation. S&L's break out of the cost reduction projections by improvement category, e.g., technology, scale-up, and volume production, proved especially helpful in assessing the relative contribution of technology.

EVALUATION OF SARGENT & LUNDY DEPLOYMENT FORECAST

The issue of deployment of CSP technologies and its effect on possible reduction of their levelized energy cost has been central to past disagreements. It has also affected DOE budget requests and congressional decisions. The NRC 2000 report [3],[6] industry's rebuttal of it [5], and the letter report of the CSP Program Peer Review [6] in late 2001[7] are often cited. Giving the full context of these statements and quoting them precisely are important to perceptions regarding objectivity versus advocacy.

Several events in August and September 2002, when S&L's assessment and the committee's work began, affected prospects for deployment of CSP technology:

1. Adoption of a large production-based incentive for four proposed solar-only CSP projects in Spain, each of which is in advanced stages of project formation. Spain has also adopted a renewable portfolio standard;
2. Adoption of a law in California mandating renewable portfolio standards; and
3. Award of a contract by ESKOM of South Africa to Nexant for a site-specific preliminary cost estimate for a 100-MW solar tower plant based on the Solar II technology approach.[8]

As discussed below, deployment is key to reducing CSP costs, and high incentives have been sought, unsuccessfully. Especially significant, therefore, is the production incentive, now law in Spain, as it is equivalent to a premium of 12 cents/kWh above the market price of electricity. Independent power producer (IPP) projects, said to be at advanced stages of project formation, may now go forward. Duke Solar and Boeing are participants in this emerging market.

In sum, deployment is viewed as central to progress in CSP technologies as it bears directly on reduction of cost.[9] S&L used SunLab's CSP deployment scenario, introducing

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[6] Reference [3], p. 65: "Finding. For all intents and purposes, power-tower and power-trough technologies could be deployed today. However, no buyers have come forward for initiating commercial operations in the United States. Recommendation. The Office of Power Technologies should limit or halt its research and development on power-tower and power-trough technologies because further refinements would not lead to deployment."

[7] Reference [6], p. 2: "With proper funding the DOE CSP Program can play an important role in catalyzing further CSP technology advances which will further improve CSP economics and market penetration." Two paragraphs later, the letter states, "The panel noted that support for the CSP Program is significantly below the level needed to contribute to the goals of the National Energy Program. Many Panel members believe the program is under-funded by about a factor of two to four times." In FY 2001, the CSP budget was $13.2 million.

[8] Bill Gould of Nexant so informed the committee and S&L, and noted that the cost estimate was to be based on a bottom-up preliminary design, and vendor quotes for all equipment. He further clarified, in response to a question, that no learning-curve methodology would be used and further noted local vendor quotes are considerably lower for key components (heliostats in particular) than predicted by the SunLab cost model. Mr. Gould also noted that preliminary designs, sized equipment lists, materials take-offs, and vendor quotes were developed by Nexant for the Solar Tres project.

[9] Reference [7]: p. 24, Slide entitled "CSP Price Reductions vs. Year." "Conclusion: It is easy to draw curves that slope downward. The issue is building the projects to allow those curves to become real."

a somewhat more conservative assumption about timing of deployment, and conservatively limiting impacts of potential improvements in technology. A possible impact of deployment on potential cost reductions in the LEC as it is influenced by scale-up of plant size, learning curves in manufacturing, and possible improvements in technology is also projected by S&L.

DOE contracted with S&L for a "due diligence-like" study. However, what S&L did was a capital cost reduction analysis based on an assumed deployment rate. The S&L study assumed a deployment strategy and then calculated a plant cost estimate. Although S&L removed reference to "due diligence-like analysis" from its report, the committee still must make this fact clear since it is part of the original S&L scope of work. In the committee's opinion neither the time nor resources allotted for the analysis was adequate for a true "due diligence-like" study, and it is clear that S&L did not do a "due diligence-like" analysis.

The S&L projection in Figure ES-1 in its report [1] shows CSP technology deployed with 100 MW each of trough and tower CSP capacity as being operational in 2004. Its report carefully notes, at the outset, the key assumptions for S&L's assessment:

1. Market expansion of trough and tower technology will require incentives to reach "market acceptance (competitive)" status.
2. Significant cost reductions will be required to reach competitiveness.
3. Deployment of CSP technology through market expansion culminates in competitiveness by 2020.

The first S&L assumption, assessing the need for market incentives, is properly identified as outside the scope of the S&L study. For the purpose of comment on deployment scenarios, the committee accepted the assumption that additional incentives would be required. The committee further notes the current international consensus that without substantial incentives, it is very unlikely that CSP trough and tower markets will evolve, and that if CSP markets are ever to reach cost competitiveness, market incentives for CSP would again have to be created. Initial deployments (1980s) of CSP technology in the SEGS trough projects were financially feasible only with substantial incentives. Later, cancellation of key financial incentives was a major factor in stalling any further CSP deployment projects that required private investment with a reduced subsidy.

The committee notes that CSP technology is not unique in the requirement for incentivizing the early market phases of emerging energy technologies [8]. The committee notes the extensive reports and study literature on these issues cited by S&L, including DOE/EE&RE's own August 2002 *Report to Congress on the Feasibility of 1,000 Megawatts of Solar Power in the Southwest by 2006* [4] and numerous other contributions to the literature, all with SunLab/DOE involvement to one degree or another over the last 4½ years [9-14].

The second S&L assumption is that substantial cost reductions will be required for CSP technologies to be competitive. The committee accepts this assumption and notes that the same reports cited above [9-14] also thoroughly address this issue.

The third S&L assumption is that incentives *will* be necessary to support deployment through market expansion. This and the nature of incentives are policy issues that S&L properly noted was outside the scope of its study. However, as it so tightly links to deployment timing and the potential for cost reductions as shown in the Executive Summary of the S&L report, the committee must comment.

The package of required additional incentives for CSP deployment is not currently in place in the United States. Even with recent progress in Spain, South Africa, and the Global Environment Facility (GEF) solar initiative, beginning in 1996 with the grant for deployment in India, no indication is given by S&L that any 100-MW CSP project is planned, let alone under construction today, roughly 2 years from the end of calendar year 2004.

The committee believes that the S&L projection of a 100-MW plant being operational in calendar year 2004 is not credible on the basis of the information given in S&L's report [1]. Absent a statement that S&L has credible proprietary knowledge to the contrary, S&L's initial deployment projections should start later in time and the curve should shift to the right, further out in time. S&L's report and projection are deficient in this regard.

S&L is well aware of the long time and cost required for project execution starting with project formation, permitting, design, engineering, procurement, and execution through commissioning and operation. Even though S&L challenged and modified SunLab's assumptions on the time between deployments of new generations of technology, the committee believes that S&L's projection is still unrealistically optimistic.

S&L certainly has the technical capability to perform a study of the time to construct these plants. It did not, however, do this and more or less arbitrarily added a year to SunLab's estimate. However, the time required to construct these new plants will probably not be significantly reduced because of the need for on-site construction. S&L's assessment of cost was based on on-site construction; it did not reflect the impact of this type of construction strategy on the time to construct. S&L did increase the time to construct from 1 year to 2 years. However, a plant would have to operate for a minimum of 2 years before detailed design for the next technology generation could be finalized, and then there would be a 2-year minimum plant construction cycle. These time delays were not factored into the deployment rate assumed in the S&L study.

Deployment at the rate used in S&L's study will also depend on industry vendors being available to provide key components. S&L did not assess the viability of vendors and did not comment on the coupling of component supply requirements to vendor capacity. A true assessment of this factor was probably beyond S&L's scope of work, but vendor availability and capacity should have been identified as items of concern for deployment at the rate identified in S&L's study.

The total amount of capital to build the number of plants in S&L's deployment forecast is also significant. It would have helped if S&L had commented on what would have to be done to reduce the risk so that investors would be willing to invest this level of capital—what would be the technical risk they would be willing to take and what would be the expected return on investment (ROI). S&L could also have commented on the type of owner needed for these plants and on the constraints these owners would place on deployment potential—e.g., IPPs, for example, are very risk averse.

In the open meeting with S&L and industry representatives on August 12, 2002, Dr. Hank Price of SunLab drew the committee's attention to the obvious impact on LECs of financial assumptions for IPP projects for high-capital projects.[10] He and SunLab colleagues [15] have focused on this issue since 1999, and they pinpoint that deployment is key.

Absent a sensitivity study on financial parameters in the S&L report [1], the committee asked that S&L run a few additional cases. The purpose of this request was merely to benchmark the impact on projected LECs[11] and to assess the benefit of currently allowed tax incentives, i.e., the 10 percent ITC and the 5-year Modified Accelerated Cost Recovery System (MACRS) rule for accelerated depreciation of capital.

The calculations show that for the SunLab scenarios evaluated by S&L, the impact on the 2020 LEC for troughs (4.3 cents/kWh) of removing only the ITC is +0.3 cents/kWh (+7.7 percent). The impact of both removing the ITC and substituting 20-year depreciation of capital for the 5-year MACRS rule is +1.8 cents/kWh (+27.6 percent).

Similar benchmarking comparisons were made for the SunLab power tower cases. There was roughly a 7 to 8 percent effect on LEC of removing the ITC, and a 20 to 28 percent effect on LEC by removing both the ITC and accelerated depreciation.

However, the set of assumptions used in the LEC calculation forced the debt/equity ratio from 59.9 percent debt to 66.5 percent debt, and it did not make much sense to the committee to allow the inference that removing one tax incentive would induce a commercial lender to accept more, higher-risk debt without raising the interest rate. If the interest rate were higher, the internal rate of return (IRR) would go down, maybe to unacceptable levels to a project developer (the borrower). Similarly the committee inferred that S&L used the same 6 percent interest on debt, implying a scenario in which a loan guarantee was in place. Without that incentive, the interest rate would presumably

[10] H. Price, SunLab, "Trough Technology R&D Opportunities," August 12 presentation to the committee, Slide 11.

[11] See S&L [1] Appendix B.8 and Appendix C. For LECs in 2002 dollars, S&L assumed a project company paying taxes; equity rate of return of 11.5 percent; interest on debt of 6 percent; debt service coverage ratio of 1.35, 20-yr debt repayment; and a project life of 30 years. Current tax incentives are investment tax credit of 10 percent and 5-yr MACRS accelerated depreciation. Debt/equity ratio varied and generally appeared in the range of 60/40. (LECs were presented without a focus on the resulting debt/equity ratio, a shortcoming in the committee's view.)

go up, and the impact on LEC would be greater still. Alternatively, in this same line of benchmarking, the impact of the roughly 12 cents/kWh premium above the market price of electricity now offered in Spain could readily be estimated. Also, a case at 10 percent interest, as assumed by DOE in its August report to Congress [4], would be illuminating.

These benchmarking comparisons demonstrate the large impact on LEC that a new CSP project would face after incentives are removed in 2020 in the scenario projected in the S&L report. It also focuses attention on the questions of competitive with what and deployed by whom after 2020. If the project financial risk were viewed as higher by the investment community at that point, it appears to the committee as unlikely that low interest rates would be available at the debt/equity ratios and IRRs used in the S&L projections of LECs. In any event, the committee concluded that Figure ES-1 in S&L's report should, at a minimum, have shown graphically at 2020 the impact on LECs of removing the tax credit incentive and accelerated depreciation. The best-case LECs for the SunLab scenarios beyond 2020 would increase at least 1.8 cents/kWh from the range of 3.5 to 4.3 cents/kWh if the currently allowed tax incentives were removed at the end of 2020.

The committee offers no finding or recommendation on the incentive policy issues, as they were outside the scope of S&L's study and therefore outside the scope of the committee's review of the S&L assessment.

ADDITIONAL COMMENTS ON THE SARGENT & LUNDY ANALYSIS

In addition to the detailed comments offered above on S&L's treatment of trough and tower technologies and on deployment, the committee submits the following comments in response to its charge to assess "the assumptions, quality, strengths and weaknesses, objectivity, and credibility" of the S&L study. The committee also offers commentary on the S&L report's Executive Summary and power generation market and deployment forecast.

Critique of the Assumptions. To a large degree, the S&L team relied on information provided by DOE, the National Renewable Energy Laboratory (NREL), Sandia National Laboratories (SNL), and members of the CSP industry for solar-related technology. The committee acknowledges SunLab's important involvement in the CSP program, its recognition of the importance of a deployment scenario to drive down costs, and its readily apparent technical proficiency as its team forthrightly and knowledgeably participated in the presentations to the committee.

S&L cross-checked the power block costs against its own data while the balance of plant (BOP) and construction-related activities were assessed using an S&L database. Although S&L claimed that its cost and performance projections came from "industrial projections," a large part of the cost information was generated using the SunLab cost model with a few changes to reflect the view of S&L.[12] The committee did not review the SunLab cost model, and its understanding of the model is based mainly on S&L's report [1] and discussions during presentations to the committee made by the S&L team and SunLab personnel.

The committee finds that given the short time and limited resources available for S&L's study, S&L along with its team of consulting experts has provided a good beginning on an important mode of analysis. S&L did a reasonable job in digesting the information available to it in the literature and was aware of the state of the art (SOA) in the U.S. CSP industry. However, the committee also notes that the CSP community is small, particularly in that it lacks a large number of commercial companies openly competing in supplying CSP. In addition, only a few CSP plants are operating, and they operate with diverse but significant government subsidies and limited sources of supply. For these reasons, it is difficult for analysts, including S&L, to obtain cost data representing a variety of perspectives, or to obtain statistically significant samples of data from which to draw inferences.

The committee notes that the S&L study relies heavily on the cost-reducing effects of deployment (bringing about benefits of economies of scale or learning) to induce future cost reductions. In other words, S&L concluded that while technological innovation alone will reduce costs to some degree, large-scale deployment is the main prerequisite for commensurate reductions in the cost of CSP generation. S&L points out, and the committee agrees, that attaining large-scale deployment is likely to require government intervention by way of, for example, tax subsidies or other financial incentives, the imposition of mandatory renewable portfolio standards, or stricter environmental policies restricting or charging for carbon emissions. Herein lies one of the biggest sources of potential controversy for this work, a sort of "chicken and egg" situation. Unless the cost of CSP is lowered there will be little incentive for increased deployment. Yet, if there is an insufficient level of deployment, the cost will not come down. S&L correctly points out that it was outside its scope of work to specify the incentives that would stimulate deployment.

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[12] The committee's understanding is that the SunLab cost model is a calculation tool allowing assessment of modeled CSP system performance and costs. Some parameters or calculated variables relate to component and subsystem efficiencies that, for example, relate to energy balance calculations. Other parameters relate to technology type, components and equipment, capacity and scale of equipment, individual costs, and learning curve equations (in some instances where no data were available). These are used to estimate future cost reductions of components due to the learning experience gained through future manufacturing and deployment experience. The SunLab cost model has been developed with substantial industry input over the years and is backed by industry experience and engineering studies, often developed under contract to SunLab or in collaborations among SunLab, industry, and consultants. Some of the supporting studies were based on actual designs of plants, or on conceptual or detailed designs of subsystems with development of sized equipment lists for subsystems at different scale, or components, and cost estimates based thereon. Costs are also sometimes based on budgetary quotes from vendors, and in other cases on cost data from construction of actual plants updated to estimate current or future costs. Other information used in the model is taken from the literature. Changes in input parameters and calculated variables in the model thus enable a projection of capital and other costs.

Further, the committee concluded that the S&L report did not present sufficient evidence of the likelihood of success for each projected advance in technology. A brief critical assessment by S&L of the status of each projected technical advance would have enabled the committee to assess the timing in the deployment scenarios.

Quality of the Sargent & Lundy Assessment. The S&L team was quite open to criticism and suggestions from the committee during the course of the study and completely revamped the second draft of the report to increase its transparency and enhance public understanding of its conclusions. The committee finds that many areas of the analysis would have benefited from even a few more months of effort.

Strengths of the Sargent & Lundy Assessment. A major strength of the S&L report is the quantification of the three major drivers that could force the LEC down from its present 10-13 cents/kWh to 3.5-6 cents/kWh in 2020. The S&L report shows that about half of the potential cost reduction for troughs and about three-fourths of the potential cost reduction for towers comes from volume production and plant scale-up. Conversely, the report shows that half of the potential cost reduction for troughs and a quarter of the potential cost reduction for towers comes from advances in technology. The S&L work clearly highlights the importance of deployment scenarios that were assumed for this study.

Another major strength of the S&L report is the identification of high- and low-leverage technologies with respect to their impact on the reduction in LEC. For example, thermal storage is shown to have a significant effect on the LEC, whereas raising the coolant temperature from that compatible with oil to a level compatible with a molten salt medium is shown to have relatively little effect on LEC.

The S&L study also illuminates the financial impact of thermal storage on both capital costs and LEC. Thermal storage greatly increases capital cost. As the size of the solar field required (the single highest cost subsystem) increases by a factor of 2.7 when 12 hours of storage is provided, the system capacity factor also increases enough to lower the LEC. Therefore, even though the LEC goes down, the capital risk increases sharply. This insight presents a dilemma in deployment strategy, as noted in the comparison of the SunLab deployment scenario presented in the S&L report, and the stated strategy being pursued in the United States by Duke Solar.

Weaknesses of the Sargent & Lundy Assessment. Before listing the weaknesses of the S&L report it is important to note that it is possible that some of the comments that follow could be addressed by increased time and resources to expand the current analysis or by taking a different approach to projecting future costs. The committee found that once shortcomings were pointed out, the S&L team did a commendable job in trying to fix those shortcomings.

While the original charge to S&L required a "due diligence-like" analysis, it is clear that the present report is does not represent such an investigation. A "due diligence" type of analysis has not yet been performed for CSP technology and would be necessary before private investors would fund a CSP plant and before a market assessment based on deployment rate could be developed.

One weakness in the S&L analysis is its assumption that new CSP facilities could be on line by 2004. Given that no such 100-MW_e facilities are at the stage needed for construction, the committee concludes that this is an unrealistic assumption. Inclusion of a later initial start would move the deployment curves out by a year or two and reduce the installed capacity in 2020, along with the expected benefits of rapid deployment. The SunLab deployment progression is based on plant operations in 2004 and then in 2006, and S&L's assessment suggests a deployment in 2004 and 2007. The committee believes that even this is unrealistic based on 2002 technology that needs major engineering redesign and optimization. The industry would have to begin immediately to deploy a first plant in 2004.

S&L has assumed several deployment rates, based on forecasts of some international project development indicators from various countries. All contemplate significant incentive programs, but there is no discussion in the S&L report as to how these incentives will come about in the United States or if they will be sufficient to induce the assumed deployment rates. There is no mention made by S&L of the total capital expenditure required to achieve deployment in the time period that it assumes for its plant cost analysis. All required capital expenditure should include investment in manufacturing capacity required, cost for project formation, and so on.

The committee concluded that the S&L report did not present sufficient evidence of the likelihood of success for each projected advance in CSP technology. Observing that work is going on, although true, is inadequate, in the committee's view. Assuming the benefits of ongoing work without assessing the probability of progress is also inadequate. The committee appreciates the time constraints, that information may be confidential, and that in-depth analysis is required later, and it suggests that S&L could have beneficially stated that.

Although both trough and tower systems analyses were performed by the same organization, S&L, using similar performance and cost guidelines, the claim is made that these two technologies cannot be compared. S&L should have attempted to identify a basis for comparing these two systems even though both concepts are at a different stage of technical development.

Although stated to be outside the scope of the S&L study, mention should have been made of potential siting issues in achieving the level of deployment that has been assumed. Siting is a critical element in the time required to construct a plant and could have a significant impact on plant construction cost. Similarly, concerns over water rights in arid regions have been noted [9]. The committee notes that SEGS-like plants require more water than do combined-cycle gas turbine plants at the same capacity. S&L did not consider the technical risks associated with the technological advances that were assumed in arriving at the capital and O&M costs for large-scale solar powered plants. In many cases, technical risks were compounded in the analysis (e.g., developing large high-temperature storage tanks capable of holding highly corrosive molten salts for 30 years when subjected to thermal cycling). S&L did not consider the probability that the efficiencies resulting from these technical developments might not occur. Also S&L did not consider possible accidents that might happen in handling very large quantities of potentially hazardous materials for more than 30 years. On the other hand, the S&L report could have discussed the experience of thermal storage in other industries and the possibility of leveraging that knowledge and technology.

Other sources of uncertainty that were not discussed in the S&L report [1] include the following:

1. There is no quantitative statement of the level of confidence S&L places in its estimates of capital or other costs.
2. There is no numerical estimate of the resulting propagation of uncertainty in the projected LECs, or how this might vary with time out to 2020.
3. There is no sensitivity study on the impact on LECs due to changes in financial parameters assumed (especially interest on debt for these capital-intensive CSP technologies).
4. There is no discussion of the impact that a lender's perception of risk in financing first-of-a-kind plants would have on interest rates charged to a project.
5. There is no discussion of how risk might be managed or reduced as CSP technology evolves.

Objectivity of the Sargent & Lundy Assessment. The committee found 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.

Credibility of the Sargent & Lundy Assessment. The committee found 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. If any fault could be found with the S&L report, it would be in the lack of critics of CSP technologies on the S&L team.

Commentary on the Executive Summary in the S&L Report. As is developed in more detail in the deployment section above, there is a problem with drawing the conclusion that "a potential market exists for CSP technology" based on the assumption that a significant deployment rate and cost reductions are forthcoming. Given that 76 percent of the cost reductions for towers relate to scale-up and volume production, it might be said that tower technologies are deployment ready today, as has been asserted previously by DOE. One could suggest that what is needed is major incentives, not additional R&D. The committee also notes that the 24 percent cost reductions for towers that are expected to come from technology advances will come at a slower pace than cost reductions from scale-up or volume production, and will require significant technical advances on thin, higher- reflectivity mirrors, novel heliostat designs, new receiver materials, and high-temperature selective surfaces. S&L also concludes that scale-up of tower technology requires total redesign and re-optimization of the field, tower, and receiver. This suggests that a significant amount of engineering is required for redesign, but the committee notes that it is unlikely to be pursued by the private sector unless significant incentives provide a way to capture at least the scale-up benefits of an initial deployment and to mitigate investment risks. Furthermore, S&L concludes that R&D in support of design, development, and testing of larger receivers, larger heliostats, and larger collector fields will reduce scale-up risk. This might also imply that a subsidized scale-up demonstration plant might be in order.

In any event, the S&L review suggests:

1. That CSP technologies are capable of producing base-load power;
2. That with sufficient size and volume, the CSP technology in the long run appears to come into the competitive range with other renewable technologies; but,
3. That significant market incentives will have to be applied to get over the scale-up and volume hurdles.

The amount of advanced R&D required to further reduce the cost of CSP technology is less of an issue in the short term, but it appears that engineering support to reduce scale-up risk is essential. However, in the longer time period, the configurations for plants built in 2010 to 2020 assume significant advanced technology. The S&L report has little or no discussion of the risks of not achieving these R&D goals nor of the magnitude of the R&D program necessary to accomplish these advances. Again, the assumption is that the appropriate incentives to encourage the needed technology development are in place or at least in the DOE budget planning process.

Commentary on Concentrating Solar Power Technology-Section 2. Although S&L's scope was limited to the assessment of tower and trough systems, other hybrid systems have been identified. S&L did not assess these hybrid systems but did describe them in Section 2 of its report. Its description of alternative systems is based only on inputs from SunLab and should not be construed as an S&L evaluation nor given the same level of credibility as the concepts that S&L spent significant time and effort evaluating. S&L should have stated this point more clearly in its report.

Overall Commentary on Power Generation Market and Deployment Forecast. In the introduction of this part of the report, S&L concludes that the most significant market entry barriers include:

1. Market expansion that will require incentives, and
2. Significant cost reductions that will be required to achieve market acceptance.

It is generally expected that a cost reduction factor of 2.5 to 3 is required for the technology to gain market acceptance. Most of this reduction, however, is due to scale-up and volume production—which are both heavily dependent on the level of deployment assumed. This is a somewhat circuitous situation.

As noted above, the committee accepted S&L's assumption that additional incentives would be required in S&L's deployment scenario. The committee turned to DOE/EE&RE's August 2002 report to Congress for a rough estimate of how large such incentives might be. The estimated cost to federal and state governments of an incentive package, developed by the CSP industry, that would deploy 1,000 MW_e of CSP capacity is between $1.5 billion and $2 billion over 14 years [4]. Industry investment is estimated at $1.8 billion [4].

Evaluation of Potential for Cost Reductions. The S&L study reviewed opportunities to reduce the cost of generating electricity for both trough and tower CSP technologies. These opportunities can be divided into three types:

1. Scale or size of plant,
2. Manufacturing and production dominated, and
3. Technology enhancement dominated.

In the first, cost reductions are projected to occur as a result of improved manufacturing methods and the economies of scaling up component production to meet deployment goals (e.g., heliostats for towers, trough mirror reflector and absorber tube modules, alignment and tracking drives and control systems, etc.). In the second and third, reductions are linked to technological innovation that improves the performance of individual components. Improved performance would increase the overall capture efficiency of solar energy, improving the dispatchability of the plant and lowering O&M requirements by increasing reliability and system lifetime. While the second type of opportunity is driven partly by deployment, it also requires a vigorous and healthy R&D program.

FINDINGS AND RECOMMENDATIONS

The committee groups its findings and recommendations into two categories:

1. Overall quality and contribution of the S&L analysis, and
2. Limitations and deficiencies in the analysis of significant concern to the committee.

Overall Quality and Contribution of the S&L Analysis

Finding: The committee finds that within the time and resources available for this study, S&L did a reasonable job in digesting the information provided to it by DOE, S&L expert consultants, and members of the CSP industry. For example, S&L's selection of component costs and economic parameters and assumptions regarding performance is well documented. Nonetheless, the committee also notes that because the CSP community is small, particularly in that it lacks a large number of commercial companies openly competing in supplying CSP, it is difficult for analysts, including S&L, to obtain cost data representing a variety of perspectives, or to obtain statistically significant samples of data from which to draw inferences.

Finding: The committee also finds that a major conclusion from the S&L analysis is well documented—that CSP systems will require significant policy-based incentives (e.g., renewable energy portfolio standards, renewable energy credits, fossil energy taxes, and other fiscal and energy policy at the federal and state level) if CSP is to provide significant future generation capacity for the United States.

Finding: The committee finds that the S&L study correctly identifies critical technical elements of trough and tower CSP technologies that require supported R&D efforts to reduce CSP levelized energy costs. For troughs these technological advances include improved receiver and mirror/reflector designs, lower pumping losses, reduced maintenance, and better thermal storage systems. For towers, improvements in the manufacture of low-cost, durable heliostats and central receivers, and the development of large-scale, high-temperature storage systems will be needed to lower costs. The committee also agrees with the S&L report that there is no single identified *technology* pathway that, if successful, would lead to CSP becoming economically competitive without significant deployment and cost reduction, the latter through learning and volume factors.

Finding: The committee agrees with the S&L conclusion that while technological innovation alone will reduce costs to some degree, large-scale deployment is the main prerequisite for commensurate reductions in the cost of CSP generation.

Limitations and Deficiencies in the S&L Analysis

Finding: The committee finds that S&L's estimates of projected capital costs and levelized energy costs (LECs) of electricity generated from solar trough and tower technologies in 2020 are 20 to 50 percent higher than current projections by SunLab and other sources. While this approach may seem to be appropriately conservative, it appears that it is primarily the choice of incrementally higher component costs, lower performance parameters, and a somewhat less aggressive deployment scenario that reduces the rate of cost reduction due to increased manufacturing volume. Regrettably, the rationale behind S&L's selections is incompletely described in its report.

Finding: The committee finds that S&L gives insufficient attention to factors that could lower costs. For example, S&L does not assess the compound risks associated with the advanced technical developments that are assumed to increase efficiencies and drive down O&M and capital costs. Nor does S&L offer sufficient information to allay the critical concern that at the current level of development effort by U.S. industry, CSP technology is unlikely to meet the performance goals needed to achieve the schedule of cost reductions assumed by S&L and SunLab in making their economic projections. In none of these areas does S&L clearly articulate the rationale and methodology used to arrive at component costs and system performance. In light of these deficiencies, the committee is unable to ascertain whether S&L's projected capital costs and LECs are more accurate than those of SunLab and others.

Finding: The committee finds that the S&L report would benefit from a clear characterization of financial uncertainty in cost analysis, including uncertainty associated with estimates of capital or other costs; how uncertainties propagate to 2020; the uncertain effects of changes in market interest on debt; the effect of and uncertainty in lenders' perception of risk; and how risk might be managed or reduced as the technology evolves. Associated with this concern, the committee finds that insufficient attention is given to the sensitivity of the projected LECs to the financial parameters used in the modeling. Given the high capital cost associated with CSP plants, special attention should be given to the sensitivity of LECs to interest on debt. The committee finds that the above omissions call into question the reliability, accuracy, credibility, and utility of the S&L analysis. However, the committee also finds that these omissions are a correctable defect in the report.

Recommendation: The committee recommends that DOE invite S&L to address the omissions and issues raised above, preferably in a management letter to DOE to be made available simultaneously with and attached to the final S&L report.

Finding: The committee is particularly concerned that the Executive Summary in the S&L report is subject to misinterpretation because of lack of description or proper qualification (particularly in the Conclusions), of the methods, assumptions, and financial parameters used in the analysis. The committee is concerned that S&L's numerical estimate of the confidence in or reliability of the projected LECs, particularly within the limitations of an executive summary, is subject to misinterpretation.

Recommendation: In conjunction with its recommendation to remedy key omissions in the S&L report, the committee urges DOE to request a revised executive summary that clarifies and points out the important limitations of the analysis methods, key assumptions, and parameters in this study.

The clear theme of the committee's findings and recommendations is that the limited charge to the S&L team, as well as the inadequate time and resources provided, resulted in an analysis and a report that do not fully answer the question that DOE seems to be asking—Do CSP plants have the potential to be competitive by 2020? Under those constraints the S&L team did not do a bottom-up cost analysis of the possibilities (or probabilities) of reducing the cost of CSP plants. Rather, it relied on a SunLab model and put in some of its own judgment. A true "due diligence" study would require four to five times more time and resources. Eventually this is the level of effort that will be required to address the long-term economic viability of CSP technology and to establish its competitive position against other renewable systems in the DOE portfolio.

REFERENCES

1. S&L (Sargent & Lundy). 2002. "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts," Draft 3, SL-5641, October. Chicago: Sargent & Lundy LLC.

2. PCAST (President's Committee of Advisors on Science and Technology). 1997. *Federal Energy Research and Development for the Challenges of the Twenty-First Century*. Report of the Energy Research and Development Panel, Executive Office of the President, Washington, D.C. (November 5).

3. NRC (National Research Council). 2000. *Renewable Power Pathways: A Review of the U.S. Department of Energy's Renewable Energy Programs.* Washington, D.C.: National Academy Press.

4. U.S. DOE/EE&RE (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy). 2002. *Report to Congress on Feasibility of 1,000 Megawatts of Solar Power in the Southwest by 2006.* Washington, D.C., August.

5. U.S. Concentrating Solar Power Industry Review Panel. 2000. "Executive Summary (June 2000)—A Rebuttal of the National Research Council's Review of the U.S. DOE's Concentrating Solar Power Program," Appendix B of Reference [7].

6. J. Tester, Massachusetts Institute of Technology, et al. 2001. Letter report to F. Wilkins, U.S. DOE, "CSP Program Peer Review," 2 pages, with 71-page Viewgraph Final Report, based on 37 viewgraph presentations by CSP participants, on November 7-9, 2001 (December 7).

7. F.H. Morse. 2000. "The Commercial Path Forward for Concentrating Solar Power Technologies: A Review of Existing Treatments of Existing and Future Markets," Morse Associates, Inc., Washington, D.C. Contract DE-AC04-94-AL85000, SAND2001-2520P, December 13.

8. M. Gielecki, F. Mayes, and L. Prete. 2000. "Incentives, Mandates and Government Programs for Promoting Renewable Energy," in *Renewable Energy 2000: Issues and Trends,* DOE/Energy Information Administration, DOE/EIA-0628 (2000), February.

9. A. Leitner, RDI Consulting. 2002. "Fuel from the Sky: Solar Power's Potential for Western Energy Supply," NREL/Bk-550-32160, A multi-client study sponsored by NREL, Sterling Energy Systems and STM Power, Golden, Colo., July.

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

11. J. Mariyappan and D. Anderson, Imperial College London. 2001. "Thematic Review of GEF-Financed Solar Thermal Projects." Monitoring and Evaluation Paper 7. Washington D.C.: Global Environment Facility.

12. Enermodal Engineering Limited (in conjunction with Marbek Resource Consultants, Ltd.). 1999. "Cost Reduction Study for Solar Thermal Power Plants." Report prepared for the World Bank, May.

13. H. Price and D. Kearney. 1999. "Parabolic Trough Roadmap: A Pathway for Sustained Commercial Development and Deployment of Parabolic Trough Technology." Springfield, Va.: National Technical Information Service. January.

14. E. DeMeo and J.F. Galdo. 1997. "Renewable Energy Technology Characterizations," USDOE/EERE and EPRI, TR-109496. Washington, D.C., and Palo Alto, Calif. December.

15. T. Mancini, G. Nakarado, G. Kolb, H. Price, and M. Prarie. 1998. "White Paper: Making a CSP Project Happen," Project Thunderbolt Report, July 8.

16. National Energy Policy Development Group. 2001. "National Energy Policy: Report of the National Energy Policy Development Group." Washington, D.C.: U.S. Government Printing Office, May.

Appendix A

Executive Summary From SL-5641

ES-1 Purpose and Scope

Sargent & Lundy LLC was contracted by the Department of Energy through the National Renewable Energy Laboratory to conduct an analysis of parabolic trough and power tower solar technology cost and performance forecasts. The results of the Sargent & Lundy analysis will be reviewed by the National Research Council Committee on 'Review of a Technology Assessment on Concentrating Solar Power Energy Systems.' 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 will compete with technologies that provide bulk power to the electric utility transmission and distribution systems. The following market entry barriers are the most significant to 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). This report focuses on the potential of cost reductions with the assumption that incentives will occur to support deployment through market expansion.

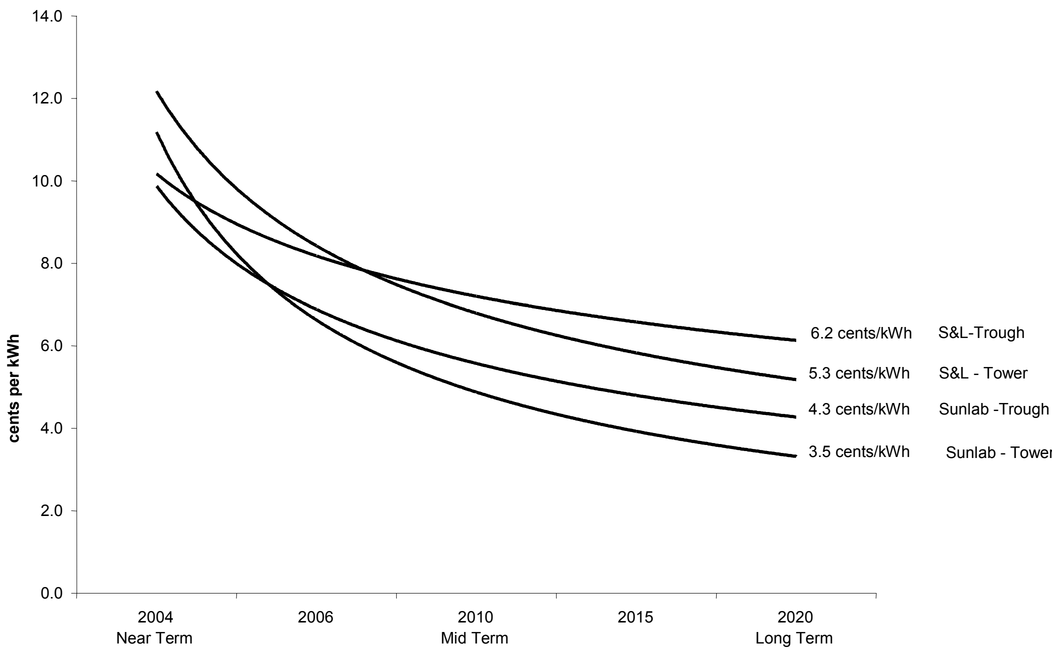
Sargent & Lundy's analysis of the cost-reduction potential of CSP technology over the next 10-20 years included the following:

- 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 Sargent & Lundy's experience, are most likely to be achieved, and a financial analysis of the cost of electricity from such future solar trough and tower plants.

ES-2 SARGENT & LUNDY'S CONCLUSIONS

Based on this analysis it is our 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. The SunLab projections are considered the best-case analysis in which the technology is optimized and a relatively high deployment rate is achieved. Sargent & Lundy independently projected capital and O&M costs, from which the levelized energy costs were derived, based on a more conservative approach whereby the technology improvements are limited to current demonstrated or tested improvements and with a lower rate of deployment than used in the SunLab model. The two sets of estimates, by SunLab and Sargent & Lundy, provide a band within which the costs can be expected to fall. Figure ES-1 highlights 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.

Figure ES-1 -Levelized Energy Cost Summary



Sargent & Lundy allocated cost reduction into the following categories: volume production (learning and improvements in manufacturing), plant scale-up (increasing size), and technology advances (RD&D). The table below highlights highlights our assessment of where trough and tower cost reduction occurs for the long-term (2020) case assuming the SunLab technology and deployment scenarios.

Cost Reduction Category	Troughs	Towers
Volume Production	26%	8%
Plant Scale-up	20%	48%
Technology Advances	54%	24%

However it should be noted that the study does not provide for a direct comparison between tower and trough technology. The two technologies are not at the same stage of commercial development and no effort was made to compare these technologies on a fully consistent basis.

ES-3 Trough Technical 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 Sargent & Lundy, the analysis bounds the future potential cost of parabolic trough electricity.

- 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 and deployment of 4.9 Gwe, trough costs approaching 4¢/kWh are feasible.

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.

ES-4 Tower Technical Summary

Because no commercial power tower plants have been built there is more uncertainty in the cost, performance, and technical risk of this technology. Consequently, Sargent & Lundy cost estimates include a 10-20% risk premium. Based on the data available to Sargent & Lundy, the analysis bounds the future potential cost of power tower electricity.

- Assuming the technology improvements are limited to current demonstrated or tested improvements and a deployment of 1.4 Gwe of installed capacity by the year 2020, tower costs should be able to drop to approxiametely 5.3¢/kWh

- Assuming the projected technical improvements are achieved by an active R&D program and deployment of 8.7 Gwe, tower costs approaching 3.5¢/kWh are feasible.
- The high temperature capabilities of tower technology has future application potential with gas turbines and combined cycles as well as for the thermo-chemical production of hydrogen and syngas. These advanced applications were not evaluated by Sargent & Lundy

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 existing proven technology is available.

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 in a lower-weight ‘stretched-membrane’ design appropriate for manufacturing. Other novel designs like inflatable/rolling heliostats are also possible. Cost reductions up to 20% as compared to current designs are possible with these approaches.
- Large 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 in 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 $146/m2 to $91/ m^2.

Appendix B

Committee Members and Staff

Committee on Review of a Recent Technology Assessment of Concentrating Solar Power Energy Systems

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[1]NAE=National Academy of Engineering

Appendix C

Presentations and Committee Activities

Committee Meeting, National Research Council, Washington, D.C., August 12-14, 2002

Due Diligence of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts: Presentation by Sargent & Lundy LLC to National Research Council
Bob Charles, Ken Davis, and Joe Smith, Sargent & Lundy LLC

National Research Council Review of Concentrating Solar Power
Frank Wilkins, Solar Thermal Team Leader, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy

Power Tower Technology
Scott Jones, Sandia National Laboratories

Trough Technology R&D Opportunities
Henry Price, National Renewable Energy Laboratory

Molten Salt Solar Power Towers
Dale Rogers, Program Manager, The Boeing Company

Duke Solar Energy: A Brief Overview of the Company Objectives
John F. Myles, Duke Solar Energy

Committee Subgroup Site Visit to Kramer Junction Operating Company, Barstow, CA, August 29, 2002

Committee Meeting, National Research Council, Washington, D.C., September 29-October 1, 2002

Presentation to NRC Committee
Sam Baldwin, Chief Technology Officer, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy

Due Diligence of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts: Presentation by Sargent & Lundy LLC to National Research Council
Bob Charles and Joe Smith, Sargent & Lundy LLC

Appendix D

A Summary of the Committee's Concerns About How the Sargent & Lundy Analysis Will Be Used

Here the committee states additional concerns that fall outside the scope of its charge but are essential to proper interpretation and use of the S&L analysis. As this report points out, the S&L cost projections depend very strongly on (1) significant deployment of trough and tower systems to bring down manufacturing costs, (2) CSP technology advances, and (3) engineering improvements required due to the extensive scaling up of CSP technology. S&L does not address what forces would bring about this large-scale expansion. Such growth requires significant government subsidies and related tax incentives, investment by the private sector, or some combination of these developments.

S&L's report also does not address the attractiveness of the CSP technologies relative to other renewable energy technologies that will also compete for favorable government tax and subsidy initiatives as well as private investment dollars. There is also no comparison to such baseline technologies as natural gas fired gas turbine combined cycles or clean coal plants and the projected performance and economics of these competing systems in 2020. Without such comparisons the S&L report's expansion scenario is not credible since the projections of future capacity depend strongly on the nature and magnitude of government subsidies as well as the relative attractiveness of CSP compared with other renewable and conventional energy.

To be more specific, the discussion of a LEC for CSP in cents/kWh and the projection of the LEC to 2020 are of little value unless a comparison is made to a conventional technology system on a consistent capital cost basis. How is the reader to know if 3.5 to 6.2 cents/kWh will be acceptable or not in 2020? Even though such an analysis was determined by DOE to be beyond the scope of the S&L study, a reference to the LEC and the capital cost for a conventional technology (e.g., natural gas) determined by the same financial analysis guidelines as S&L used in the CSP evaluations would have been valuable. This is not as much a criticism of S&L as it is a comment on the narrowness of the charge to S&L.

Although a study of competitive systems (i.e., natural gas, coal, other renewable, and nuclear) was outside the scope of the S&L study, it is critical that competitive systems at least be identified. It would have been extremely helpful if a range of competitive capital costs and LECs were provided in order to put the costs of the CSP systems into perspective.

These and other considerations would be essential and routine elements in a financial due diligence analysis prior to private investment in CSP. As the committee acknowledges above, S&L initially was asked to conduct a "due diligence-like" analysis in which these considerations would be relevant. Similarly, an in-depth technical due diligence would be considerably more complex than the S&L treatment and would be based on a higher level of site-specific, detailed design, engineering, construction, and procurement plans; price quotes rather than budgetary estimates from evaluated and qualified vendors; permit requirements; access to power grids and transmission rights; and terms of power purchase agreements and elements of risk therein. Due diligence exercises at earlier phases of project formation usually would address most or all of these issues at lower levels of confidence, and the degree of confidence would be stated at each level of estimate and analysis. This is well settled practice in engineering and due diligence assessments.

Finding: Like all other new energy technologies, CSP faces tough competition from currently lower-cost fossil fuel alternatives, particularly natural gas. Because of low capital costs, high fuel conversion efficiencies, and most importantly, currently low fuel costs with minimal constraints on deliverability, natural gas combined-cycle plants represent the lowest cost option for adding new or replacing old capacity in a size range that overlaps CSP trough and tower technology.

Finding: Because CSP receives its energy from an indigenous renewable resource, its fuel-cycle-related costs are imbedded in the initial capital investment and hence fully insulated against international price instabilities and deliverability problems. Unfortunately, in today's energy markets, this positive attribute alone does not provide a sufficient incentive to lead to investment in renewable alternatives.

Recommendation: In light of national objectives that include increased energy security, lowering dependence on imported oil and gas to become more energy independent, and lowering environmental impacts both locally and globally, DOE should conduct a technical and economic analysis of its entire portfolio of renewable energy conversion systems with a uniform set of performance and financial assumptions. This analysis could then be compared against alternative conventional systems that will be available in the time frame when renewable systems would be employed.

Recommendation: The committee recommends that a comparison of CSP with other renewable energy technology options be carried out that connects to regional issues—including resource grade and quality, capital and O&M costs, ease of siting and deployment, and energy demand—to national goals as articulated in the National Energy Plan [16] and DOE's strategic planning. For example, the high-grade direct insolation resource of the arid Southwest represents a substantial renewable asset in a region with a growing demand for electric power. There are also considerable federal and state lands in the Southwest that are not suitable for agriculture or forestry that would make attractive sites for CSP plants.

Recommendation: Upon successfully completion of the intent of the previous two recommendations, and if the conclusion is positive for CSP plants, the committee recommends that DOE place greater emphasis on supporting U.S. industry by testing critical components for CSP deployment. This effort may include enhancing the current capacity of SunLab to conduct standardized tests to validate the performance and durability of reflectors, heliostats, receivers, storage, and absorber elements to ensure reliability for industrial developers. Furthermore, upgrading current CSP resource assessment capabilities to aid the siting of new generation plants will be needed to achieve the deployment goals. However, this action should not be taken until the commercial viability of CSP technology has been established.