Appendix E

Evaluation of Technology Improvements and Capital Cost Projections – Tower

E. EVALUATION OF TECHNOLOGY IMPROVEMENTS AND CAPITAL COST PROJECTIONS – TOWER

CONTENTS

E. EVALUATION OF TECHNOLOGY IMPROVEMENTS AND CAPITAL COST PROJECTIONS – TOWER

E.1 COST DRIVERS

The direct cost of a solar power tower is divided into the following major categories:

- Structures and Improvements
- Heliostat Field
- Receiver System
- Tower + piping system
- Thermal Storage System
- Steam Generator System
- Electric Power Generation System
- Master Control System
- Balance-of-plant

The solar field, electric power block, receiver, and thermal storage encompass approximately 80% of the total direct costs as shown in Figures E-1 and E-2. The major cost component is the heliostat field, which encompasses 43% of total costs for Solar Tres and 47% of total cost for Solar 220. The next two categories are electric power block (13% for Solar Tres and 20% for Solar 220) and receiver (18% for Solar Tres and 8% for Solar 220). Our review is to determine if the capital cost estimates prepared by SunLab were within a reasonable range based on our review of available studies and reports, the SunLab cost estimate and our due diligence experience. The focus was primarily on the major cost categories: heliostats, electric power block, and receiver. The cost estimate reductions projected by SunLab from 2004 to 2020 are shown in Figure E-3.

Figure E-1 — Capital Cost Categories for Solar Tres

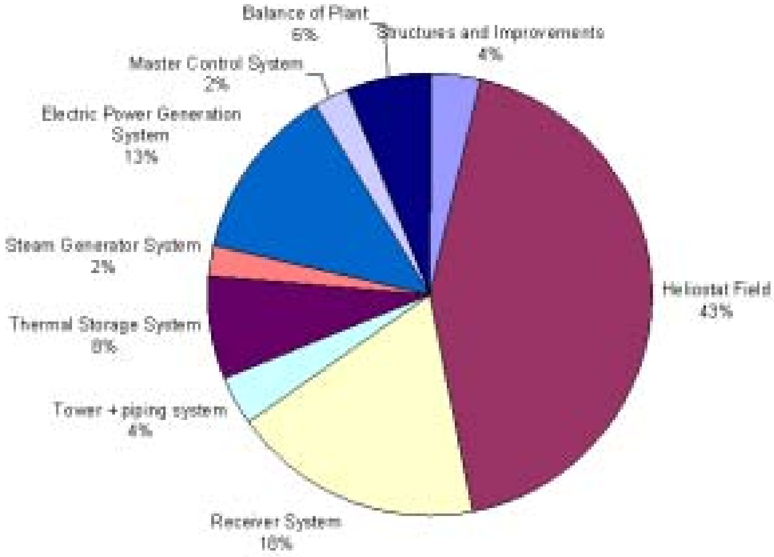


Figure E-2 — Capital Cost Categories for Solar 220

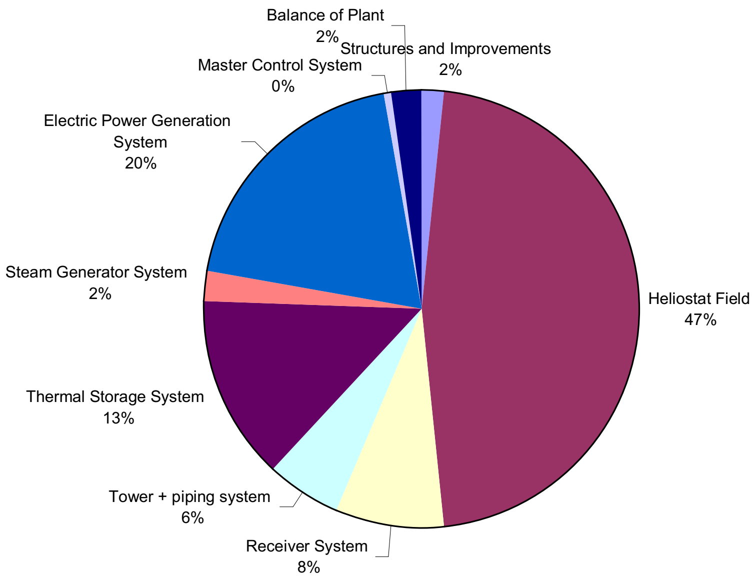
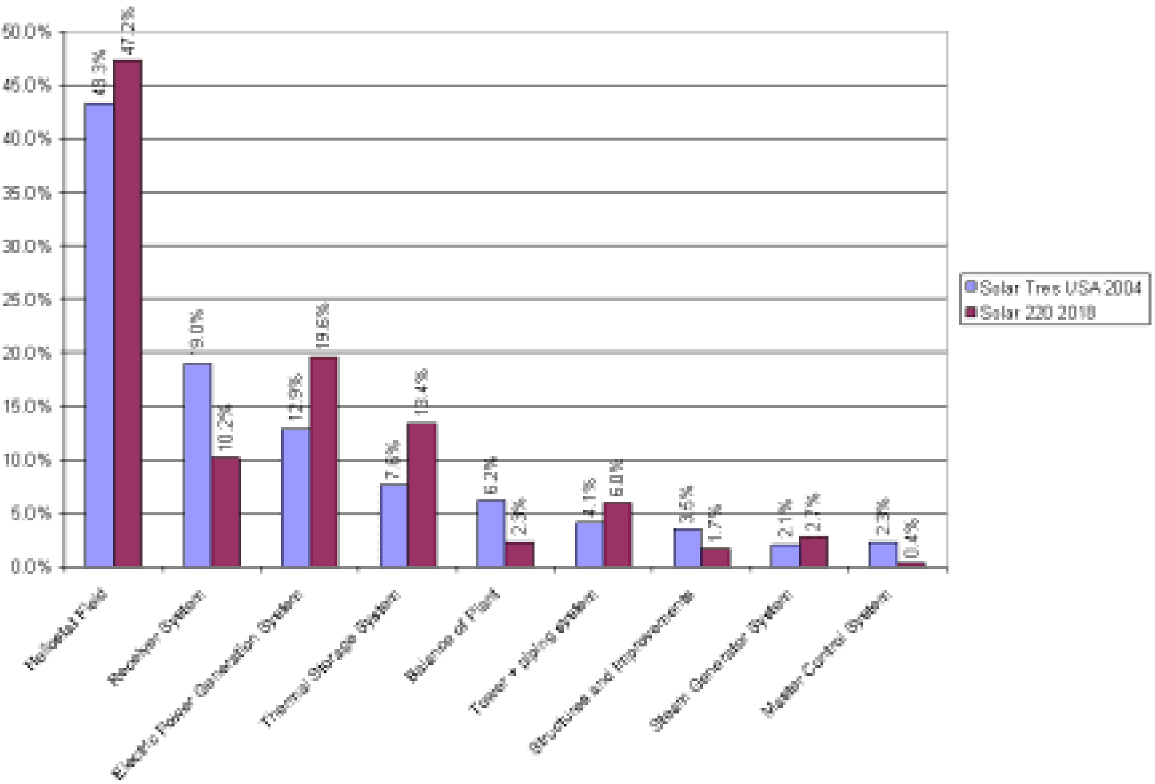


Figure E-3 — Direct Capital Cost Power Tower Solar Plant (Projected Years 2004 and 2020)



The total installed cost estimate by SunLab is shown in Table E-1. The values presented for Solar Tres throughout the report assume that the plant is located in the United States and not in Spain to provide more consistent comparison. The cost estimate by S&L based on our review of the major cost drivers is shown in Table E-2. Shaded areas indicate differences between the S&L and SunLab estimates.

Table E-1 — SunLab Capital Cost Estimate (Deployment of 8.7 GWe)

	Case	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 220
	Year	2004	2006	2008	2012	2018
Description	**Contingency**					
Land Area, km^2		1.1	3.4	6.6	13.7	13.9
Field Area, m^2		231,000	709,000	1,311,000	2,600,000	2,642,000
Structures & Improvements, $M	20%	$2.8	$4.1	$5.3	$7.2	$7.2
Heliostat Field, $M	5%	$33.5	$89.8	$139.8	$249.6	$198.8

	Case	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 220
	Year	2004	2006	2008	2012	2018
Description	**Contingency**					
Receiver, $M	10%	$14.0	$19.8	$25.0	$36.9	$34.4
Tower & Piping, $M	10%	$2.8	$7.0	$11.9	$24.3	$24.3
Thermal Storage, $M	10%	$5.9	$18.7	$28.9	$56.3	$57.2
Steam Generator, $M	10%	$1.6	$3.7	$5.8	$9.4	$9.3
Electric Power Block, $M	10%	$10.0	$24.5	$40.0	$64.0	$83.6
Master Control System, $M	10%	$1.8	$1.8	$1.6	$1.6	$1.6
Balance-of-plant, $M	10%	$4.8	$6.5	$7.8	$9.6	$9.9
Direct Costs, $M		$77.3	$175.9	$266.1	$458.8	$426.3
Engineering, Management & Development (7.8%), $M		$6.6	$13.7	$20.8	$35.8	$33.3
Land (no cost for Solar Tres and Solar 50) ($5,000 per hectare), $M		$0	$0	$3.3	$6.9	$7.0
Contingency, $M	7.7%	$6.3	$13.5	$20.2	$34.1	$34.3
Risk Pool (Only for Solar Tres) – (10%), $M		$7.7	$0	$0	$0	$0
Total Cost – SunLab, $M		$97.4	$203.1	$310.3	$535.6	$599.9
Total Cost – SunLab, $/kWe		$7,135	$4,063	$3,103	$2,678	$2,272

Table E-2 — S&L Capital Cost Estimate (Deployment of 2.6 GWe)

	Case	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 200	Solar 220
	Year	2004	2007	2010	2015	2020	2020
Description	**Contingency**						
Land Area, km^2		1.1	3.4	6.6	13.7	13.7	13.9
Field Area, m^2		244,966	742,703	1,366,100	2,667,099	2,667,099	2,789,322
Structures & Improvements, $M	20%	$2.8	$4.1	$5.3	$7.2	$7.2	$7.2
Heliostat Field, $M	10%	$39.1	$111.7	$182.7	$330.0	$312.1	$263.0
Receiver (Boeing), $M	10%	$16.0	$26.0	$34.0	$46.0	$46.0	$48.0

	Case	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 200	Solar 220
	Year	2004	2007	2010	2015	2020	2020
Description	**Contingency**						
Tower & Piping, $M	10%	$2.8	$7.0	$11.9	$24.3	$24.3	$24.3
Thermal Storage, $M	10%	$5.9	$18.7	$28.9	$56.3	$56.3	$57.2
Steam Generator, $M	10%	$1.6	$3.7	$5.8	$9.4	$9.4	$9.3
Electric Power Block, $M	10%	$7.6	$18.6	$30.8	$46.2	$46.2	$61.8
Master Control System, $M	10%	$1.8	$1.8	$1.6	$1.6	$1.6	$1.6
Balance-of-plant, $M	10%	$10.0	$24.5	$36.7	$33.8	$33.8	$36.5
Direct Cost, $M		$87.7	$216.1	$337.5	$554.7	$536.8	$508.9
Engineering, Management & Development – (15%),$M	20%	$15.5	$38.1	$59.6	$97.9	$97.9	$89.9
Land (no cost for Solar Tres and Solar 50) ($5,000 per hectare), $M		$0.0	$0.0	$3.3	$6.9	$6.9	$7.1
Contingency, $M	10%	$12.1	$29.6	$46.2	$75.8	$74.0	$69.6
Cost Reduction Contingency, $M	15%		$15.6	$14.2	$18.1	$2.7	$15.2
Risk Pool – Upper (10% for Solar Tres /5% for Solar 50), $M		$8.8	$10.8	$0.0	$0.0	$0.0	$0.0
Total Cost – S&L, $M		$124.1	$310.3	$460.8	$753.3	$718.2	$690.5
Total Cost – S&L, $kWe		$9,090	$6,205	$4,608	$3,766	$3,591	$3,139

E.2 DEPLOYMENT

The deployment projections used by SunLab to develop their cost estimate is based on deployment (commercial operation) of Solar Tres in 2004 with successive initial deployments in 2006 for Solar 50, 2008 for Solar 100, 2012 for Solar 100 and 2018 for Solar 220 (see Table E-3). Deployment is dependent on Solar Tres being successful and on incorporating lessons learned into Solar 50 design. The duration between initial deployments from Solar Tres to Solar 50 and from Solar 50 to Solar 100 in the SunLab model allows only one year of operation. The duration between initial deployments should be at least two years to allow time to resolve operational issues, achieve dependable steady-state operation, and operate for a reasonable amount of time. The

S&L deployment projection taking these issues into consideration is shown in Table E-4. S&L's projection is more conservative than the SunLab projection of 8.7 GWe. The S&L projected range is from a maximum deployment of 4.7 GWe to a minimum deployment of 1.2 GWe. The S&L base case is a deployment of 2.6 GWe.

Table E-3 — Power Tower Deployment Projection – SunLab

	MWe\ Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Installed (MWe)	Cumulative (MWe)
Solar Tres	13.5	1																	13.5	14
Solar 50	50			1	2	3													300	314
Solar 100	100					1	2	3	4	4	4	4	2	2	1				2,700	3,014
Solar 200	200									1	1	1	3	3	4	4	5		4,400	7,414
Solar 220	220															1		5	1,320	8,734
Total		13.5	0	50	100	250	200	300	400	600	600	600	800	800	900	1,020	1,000	1,100	8,734	

Table E-4 — Power Tower Deployment Projection –S&L

	MWe\ Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Installed (MWe)	Cumulative (MWe)
4.7 GWe																				
Solar Tres	13.5	1																	13.5	14
Solar 50	50				1		1	2	2										300	314
Solar 100	100							1		1	2	2	3	4					1,300	1,614
Solar 200	200											1		1	2	3	3	3	2,600	4,214
Solar 220	220															1		1	440	4,654
Total		13.5	0	0	50	0	50	200	100	100	200	400	300	600	400	820	600	820	4,654	
2.6 GWe																				
Solar Tres	13.5	1																	13.5	14
Solar 50	50				1		1	1	1	2	2								400	414
Solar 100	100							1		1	1	1	2	2	2				1,000	1,414
Solar 200	200												1		1	1	1	2	1,200	2,614
Solar 220	220																			
Total		13.5	0	0	50	0	50	150	50	200	200	100	300	200	300	200	200	400	2,614	
1.2 GW																				
Solar Tres	13.5			1															13.5	14
Solar 50	50						1		1	1	1								200	214
Solar 100	100										1		1	1	1				400	614
Solar 200	200														1		1	1	600	1,214
Solar 220	220																		0	0
Total		0	0	13.5	0	0	50	0	50	50	150	0	100	100	300	0	200	200	1,214	

E.3 EFFICIENCY

E.3.1 Efficiency Calculation

The Solar Field is defined by the collector area in square meters (m^2), which can be estimated by the simplified equation:

$$C = \frac{(kW_d \times CF \times h)}{eff \times I}$$

Where:

C = Collector area square meters (m^2)

kW_d = electric generation design capacity, kilowatts

CF = Capacity Factor = kW_eh actual /(kW_d x 8,760)

h = hours per year (8,760)

eff = net annual efficiency, Solar to Electric

I = annual insolation (kWh_t/m^2)

kW_e = kilowatts electric

kWh_t = kilowatts thermal

For a given plant size and capacity factor, the net annual efficiency is the determining factor in the collector area; as the efficiency increases, the collector area decreases on the same percentage basis.

The annual net solar-to-electric efficiency determination and the efficiency of Solar Tres are shown in Table E-5.

Table E-5 — Annual Solar-to-Electric Efficiency

Solar Field	
Mirror Reflectivity	93.5%
Field Optical Efficiency	64.6%
Field Availability	98.5%
Mirror Corrosion Avoidance	100%
Mirror Cleanliness	95%
Field High Wind Outage	99%
Annual Heliostat Field Efficiency (HFE)	56.0%

Annual Receiver Efficiency (RE)	78.3%
Annual Piping Efficiency (PE)	99.5%
Annual Thermal Storage Efficiency (TSE)	98.3%
Annual Electrical Steam Turbine Efficiency (ST)	40.3%
Startup Efficiency (SE)	99.5%
Parasitics (P) (1 - % auxiliary power consumed by plant)	86.4%
Plant-wide Availability (A)	92.0%
Annual solar-to-electric efficiency (E_{net}) (E_{net}) = (HFE) x (RE) x (PE) x (TSE) x (ST) x (SE) x (P) x (A)	13.7%

The collector area is directly proportional to the plant megawatt size and the capacity factor, as evident in the preceding equation. There are economies of scale associated with increasing the plant megawatt size. To provide generation during non-solar periods and thereby increase the plant capacity factor, thermal storage is required. Thermal storage can reduce plant thermal losses by reducing the number of steam turbine start-stop cycles and decreasing the use of electrical heat tracing during no-load periods.

E.3.2 Net Annual Solar-to-Electric Efficiency Impact on Cost

The net annual solar-to-electric efficiency has a significant impact on the size of the collector field and hence the cost. The largest increase in efficiency is the step change from Solar Two to Solar Tres as shown in Figure E-4 (7.9% to 13.1 %). The comparison of the SunLab and S&L projections for efficiency improvements is shown in Tables E-6 and E-7. In addition, S&L considered a worst case with limited improvements in efficiencies, which are given in Table E-8. The cost reduction based on S&L's evaluation of the SunLab reference case is shown in Section E.3.6. The net annual solar-to-electric efficiency impact on collector field cost for each change in size plant is shown in Section E.3.6.

Table E-6 – SunLab Net Solar-to-Electric Efficiency

	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Heliostat Field Efficiency	50.3%	56.0%	56.5%	56.3%	56.1%	57%
Mirror Reflectivity	90.7%	93.5%	94.0%	94.0%	95.0%	95.0%
Field Efficiency	62.0%	64.6%	64.6%	63.7%	62.8%	62.8%
Field Availability	98.0%	99.5%	99.0%	99.5%	99.5%	99.5%

	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Mirror Corrosion	97.0%	100%	100%	100%	100%	100%
Mirror Cleanliness	95.0%	95.0%	95.0%	96.0%	96.0%	97.0%
Field High Wind Outage	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%
Receiver Efficiency	76%	78.3%	80.9%	83.1%	83.5%	82.0%
Piping Efficiency	99.0%	99.5%	99.5%	99.9%	99.9%	99.9%
Thermal Storage Efficiency	97.0%	98.3%	99.5%	99.5%	99.5%	99.5%
EPGS Efficiency	32.6%	40.3%	41.8%	42.3%	42.8%	46.1%
Parasitic (Auxiliary Power) Efficiency	73.0%	86.4%	90.0%	90.0%	90.0%	90.0%
Plant Wide Availability	90.0%	92.0%	94.0%	94.0%	94.0%	94.0%
Net Annual Solar-to-Electric Efficiency	7.9%	13.7%	16.1%	16.6%	16.9%	18.1%

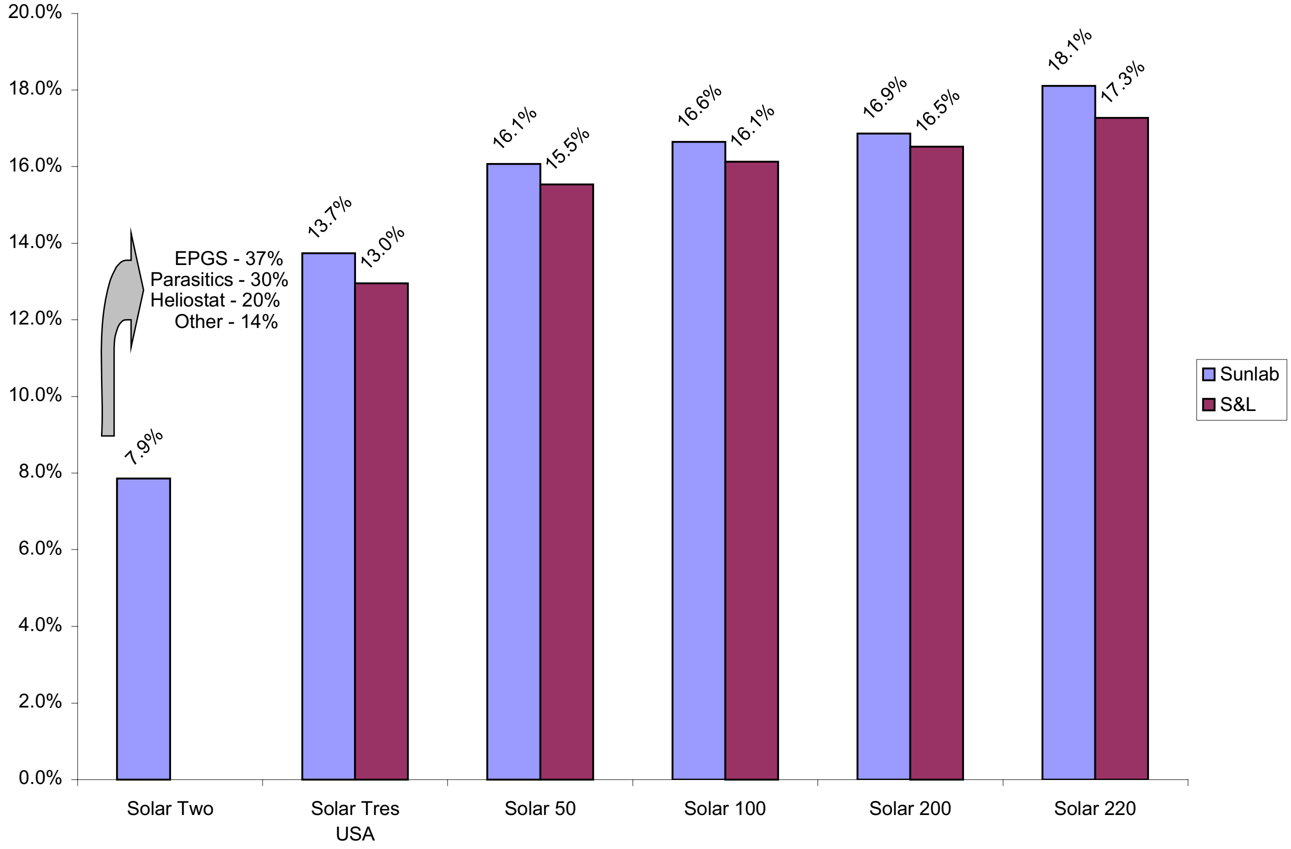
Table E-7 — Sargent & Lundy Net Solar-to-Electric Efficiency — with Anticipated Improvements

	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Heliostat Field Efficiency	50.3%	56.0%	56.5%	56.0%	55.2%	55.2%
Mirror Reflectivity	90.7%	93.5%	94.0%	94.0%	94.0%	94.0%
Field Efficiency	62.0%	64.6%	64.6%	63.7%	62.8%	62.8%
Field Availability	98.0%	99.5%	99.0%	99.5%	99.5%	99.5%
Mirror Corrosion	97.0%	100%	100%	100%	100%	100%
Mirror Cleanliness	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Field High Wind Outage	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%
Receiver Efficiency	76.0%	78.3%	80.9%	83.1%	83.5%	82.0%
Piping Efficiency	99.0%	99.5%	99.5%	99.9%	99.9%	99.9%
Thermal Storage Efficiency	97.0%	98.3%	99.5%	99.5%	99.5%	99.5%
EPGS Efficiency	32.6%	38.0%	40.4%	41.2%	42.6%	45.4%
Parasitic (Auxiliary Power) Efficiency	73.0%	86.4%	90.0%	90.0%	90.0%	90.0%
Plant Wide Availability	90.0%	92.0%	94.0%	94.0%	94.0%	94.0%
Net Annual Solar-to-Electric Efficiency	7.9%	13.0%	15.5%	16.1%	16.5%	17.3%

Table E-8 – Sargent & Lundy Net Solar-to-Electric Efficiency — with Limited Improvements

	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Heliostat Field Efficiency	50.3%	54.3%	54.6%	54.1%	53.3%	53.3%
Mirror Reflectivity	90.7%	90.7%	90.7%	90.7%	90.7%	90.7%
Field Efficiency	62.0%	64.6%	64.6%	63.7%	62.8%	62.8%
Field Availability	98.0%	98.5%	99.0%	99.5%	99.5%	99.5%
Mirror Corrosion	97.0%	100%	100%	100%	100%	100%
Mirror Cleanliness	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Field High Wind Outage	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%
Receiver Efficiency	76.0%	78.3%	78.3%	78.3%	78.3%	78.3%
Piping Efficiency	99.0%	99.5%	99.5%	99.9%	99.9%	99.9%
Thermal Storage Efficiency	97.0%	98.3%	98.3%	99.5%	99.5%	99.5%
EPGS Efficiency	32.6%	38.0%	40.4%	41.2%	42.6%	42.6%
Parasitic (Auxiliary Power) Efficiency	73.0%	86.4%	90.0%	90.0%	90.0%	90.0%
Plant Wide Availability	90.0%	92.0%	92.0%	92.0%	92.0%	92.0%
Net Annual Solar-to-Electric Efficiency	7.9%	12.6%	14.0%	14.4%	14.6%	14.6%

Figure E-4 — Comparison of Annual Solar-to-Electrical Efficiency Technology Step Changes: SunLab vs. S&L



E.3.3 Steam Cycle (Electric Power Block) Efficiency

Increases in the steam cycle efficiency provide the largest cost reduction to the collector field cost. Discussion of the efficiency improvements is provided in Section E.6.2.

E.3.4 Collector and Receiver Efficiency

Increases in collector and receiver efficiency provide the next largest cost reduction to the collector field cost. Discussion of the efficiency improvements for the collector system is provided in Section E.4.2 and for the receiver system in Section E.7.2.

E.3.5 Thermal to Power Plant Efficiency — Parasitics

The efficiency improvements are based on 16 hours of thermal storage for Solar Tres and Solar 50 and 13 hours for Solar 100 and Solar 200. The storage allows the plant to operate during non-insolation periods, thereby reducing thermal losses by minimizing the energy loss during plant start/stop cycles (thermal to plant power efficiency) and HTF heating (parasitics) during off-line periods. Even though efficiency improvements can be gained by thermal storage, additional direct costs will be incurred. First, the cost of the storage system is estimated by SunLab to be $4,940/kWe for Solar Tres, and second, the collector area required will be more than doubled for 16 hours storage capability. The 16 hours of thermal storage is reasonable since Solar Two successfully demonstrated operation with 3 hours of thermal storage. Thermal storage is discussed in greater detail later in this report.

E.3.6 Net Annual Solar-to-Electric Efficiency Impact on Cost (SunLab Model)

**Table E-9 — Solar Two to Solar Tres:
Net Annual Solar-to-Electric Efficiency Impact on Cost (SunLab)**

	Solar 2	Solar Tres
Plant Size – Electrical, MWe	10	13.7
Plant Size – Thermal, MWt	42	120
Heliostat Capital Cost, $M	—	33.5
Field Area, m^2	81,400	231,000
Heliostat Cost per m^2	—	$145
Net Solar-to-Electric Efficiency	7.9%	13.7%
The efficiency improvement is a cost savings of $19.3 M (reduction of the field by 133,204 m^2).		
The improvement is based on the following system improvements:		
Heliostat – 1.4% Receiver - 0.4% EPGS – 2.6% Parasitics – 2.1% Thermal Storage – 0.2% Piping – 0.1% Availability – 0.3%		

Table E-10 — Solar Tres to Solar 50: Net Annual Solar-to-Electric Efficiency Impact on Cost (SunLab)

	Solar Tres	Solar 50
Plant Size – Electrical, MWe	13.7	50
Plant Size – Thermal, MWt	120	380
Heliostat Capital Cost, $M	33.5	89.8
Field Area, m^2	231,000	709,000
Heliostat Cost per m^2	$145	$127
Net Solar-to-Electric Efficiency	13.7%	16.1%
The efficiency improvement is a cost savings of $13.4 M (reduction of the field by 105,689 m^2)		
The improvement is based on the following system improvements:		
Heliostat – 0.2% Receiver - 0.5% EPGS – 0.6% Parasitics – 0.6% Thermal Storage – 0.2% Piping – 0.1% Availability – 0.3%		

Table E-11 — Solar 50 to Solar 100: Net Annual Solar-to-Electric Efficiency Impact on Cost (SunLab)

	Solar 50	Solar 100
Plant Size – Electrical, MWe	50	100
Plant Size – Thermal, MWt	380	700
Heliostat Capital Cost, $M	89.8	139.8
Field Area, m^2	709,000	1,311,000
Heliostat Cost per m^2	$127	$107
Net Solar-to-Electric Efficiency	16.1%	16.6%
The efficiency improvement is a cost savings of $4.2 M (reduction of the field by 39,488 m^2)		
The improvement is based on the following system improvements:		
Heliostat – minus 0.1% (decrease in performance) Receiver - 0.6% EPGS – 0.2% Parasitics – 0% Thermal Storage – 0% Piping – 0% Availability – 0%		

Table E-12 — Solar 100 to Solar 200: Net Annual Solar-to-Electric Efficiency Impact on Cost (SunLab)

	Solar 100	Solar 200
Plant Size – Electrical, MWe	100	200
Plant Size – Thermal, MWt	700	1,400
Heliostat Capital Cost, $M	139.8	249.6
Field Area, m^2	1,311,000	2,606,000
Heliostat Cost per m^2	$107	$96
Net Solar-to-Electric Efficiency	16.6%	16.9%
The efficiency improvement is a cost savings of $4.4 M (reduction of the field by 46,260 m^2)		
The improvement is based on the following system improvements:		
Heliostat – minus 0.1% (decrease in performance) Receiver - 0.1% EPGS – 0.2% Parasitics – 0% Thermal Storage – 0% Piping – 0% Availability – 0%		

Table E-13 — Solar 200 to Solar 220: Net Annual Solar-to-Electric Efficiency Impact on Cost (SunLab)

	Solar 200	Solar 220
Plant Size – Electrical, MWe	200	220
Plant Size – Thermal, MWt	1,400	1,400
Heliostat Capital Cost, $M	249.6	198.8
Field Area, m^2	2,606,000	2,642,000
Heliostat Cost per m^2	$96	$75
Net Solar-to-Electric Efficiency	16.9%	18.1%
The efficiency improvement is a cost savings of $13.1 M (reduction of the field by 175,160 m^2).		
The improvement is based on the following system improvements:		
Heliostat – 0.3% Receiver – minus 0.4% EPGS – 1.3% Parasitics – 0% Thermal Storage – 0% Piping – 0% Availability – 0%		

E.4 COLLECTORS

The first plants (Solar Tres and Solar 50) will use the 95-m^2 heliostats. The heliostat size will be increased to 148 m^2 for Solar 100. S&L's evaluation focused on the capital costs and cost improvement for the 148-m^2 heliostat. The S&L review is primarily based on the SunLab model, the detailed cost models developed by AD Little (Arthur D. Little, 2001), Advanced Thermal Systems (1996), Solar Kinetics (1996), and the Peerless-Winsmith drive cost and technology improvement studies (Peerless-Winsmith 1996, 1999). The 150-m^2 heliostat was then compared against the 95-m^2 heliostat. We reviewed the major cost components and provided a discussion of the assumptions and reasonableness of the cost estimate in Section E.5.

AD Little (ADL) was contracted by the DOE to prepare a detailed cost estimate for the current 150-m^2 heliostat design from Advanced Thermal Systems (ATS). The study was based on detailed design drawings, material takeoff, and proven assembly techniques (Advanced Thermal Systems 1996). Manufacturers and vendors were contacted to develop and validate material costs. ADL used the detailed design information from ATS[*] (1996) to estimate the costs. This bottoms-up cost estimate is fairly rigorous and provides a fairly accurate cost estimate. S&L compared and evaluated the detailed cost models and developed a cost estimate.

E.4.1 Direct Capital Cost

The cost summary of material, labor, overhead, and profit for the SunLab cost estimate is compared to the ADL cost estimate in the Table E-14. A composite cost estimate was developed by S&L based on evaluation of the differences between the cost estimates.

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[*] The heliostat was developed by ATS under contract with the DOE. DOE funded the development of the 'second-generation' 53-m^2 heliostat. ARCO funded the design, development, and first prototype 95- and 148-m^2 trackers for use as heliostats or PV trackers. Advanced Thermal Systems is a small company formed in 1985 by former ARCO engineers with licensing rights for the tracker technology. The early design was optimized to use the maximum number of commodity parts and provide the lowest possible cost for near-term deployment. Approximately 1000 solar trackers of this basic design have been built. Most were the 95-m^2 units. One hundred eight of the heliostats used at Solar Two were second-hand ATS-built trackers.

Figure E-5 — Heliostat Cost Drivers

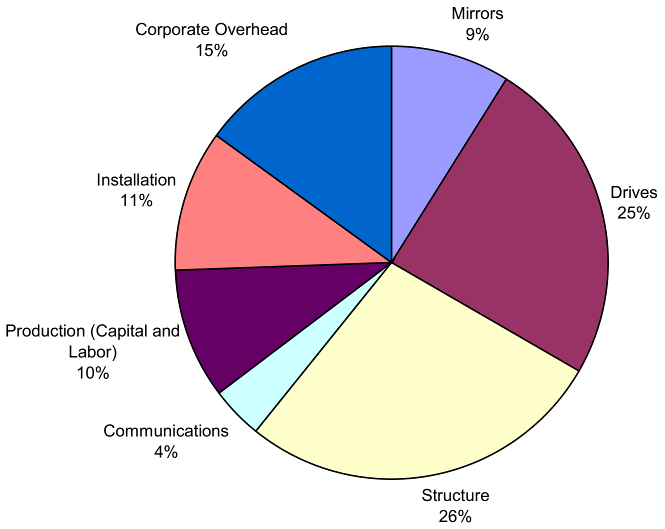


Table E-14 — 148 m^2 Heliostat Direct Capital Cost: Comparison of SunLab and ADL

Summary of Cost Comparison	**SunLab**	**ADL**	**S&L**	**Discussion**
Collector Area (m^2)	227,000	444,000	444,000	
Quantity (units)	1,534	3,000	3,000	
Mirrors	$1,924	$1,976	$1,976	Mirror costs are based on vendor quotes and are the same as ADL
Drive (azimuth)	$4,035	$4,000	$4,035	Drive costs are based on vendor quotes.
Drive (elevation)	$1,250		$1,250	ADL cost estimate included a dual drive (azimuth and elevation).
Structural Steel, Pedestal, & Other	$5,887	$5,598	$5,887	The composite of structural steel, pedestal and other costs are about the same
Communications	$875		$875	The ADL estimate did not include communications.
Labor	$800	$1,552	$800	ADL included indirect costs whereas SunLab only includes direct costs. We used SunLab direct costs and increased Overhead & Profit to 20% to cover indirect costs.

Summary of Cost Comparison	SunLab	ADL	S&L	Discussion
Capital Equipment and Tooling	$863	$301	$912	The difference is attributed to ADL basing their cost on a supplier setting up a manufacturing facility whereas SunLab's estimate is based on a local assembly shop associated with the construction project. (See Appendix E.5.9)
Other Production Costs	$419	$172	$419	SunLab other includes 3% for shipping, whereas ADL did not define other.
Total Fabrication Costs	$16,053	$13,599	$16,102	
Corporate Overhead	$2,408	$3,334	3,211	SunLab is based on 15%, whereas ADL uses 25%. The S&L estimate is based on 20% since a local production shop will be set up as part of construction until the market for heliostats opens up. This will reduce corporate overhead costs.
System Cost	$18,461	$16,933	$19,322	
Installation	$950	$2,036	$1,426	ADL estimate is more reasonable and higher than the SunLab estimate.
Field Wiring	$877		$877	The ADL estimate did not include field wiring; therefore, the SunLab cost estimate for field wiring was added for comparison
Total Installed Cost	$20,288	$18,969	$21,688	
Total Installed Cost per m^2 for 148-m^2 heliostat	$137	$128	$146	The estimated cost range is between $137 (SunLab estimate) and $146 (S&L estimate) for initial deployment of 148-m^2 heliostats. The difference between S&L and ADL is 7%.

The cost estimates for both SunLab and ADL are based on the ATS detailed design drawings and material quantities. The material costs are essentially the same. The differences are labor, overhead, and capital for equipment and tooling. The S&L estimate is based on a local production facility being developed at or near the construction site. This assumption is reasonable for the first several deployments since it will be difficult to entice a reputable manufacturer to establish a production facility without firm commitments and significant quantities. SunLab used a contingency of +5%. S&L used a contingency of +10% based on the uncertainties associated with estimating costs.

Therefore, S&L estimates that the direct cost estimate for initial deployment of a 148-m^2 heliostat is $146 per m^2, plus a contingency of 10% ($161 per m^2).

The main difference between the 95-m^2 and 148-m^2 heliostat is size, therefore it is reasonable to estimate the 95 m^2 cost by extrapolating the 148 m^2 cost using a scaling factor. SunLab used a scaling factor of 0.8 as shown in Table E-9. As a component, structure, or plant increases in size the increase in cost is not linear. Typical scaling factors, based on industry experience, are about 0.7 (S&L uses 0.67 to 0.72 based on our experience with scaling of power generating plants, Boeing uses 0.7 to 0.8 based on their industrial experience).

The direct cost estimate for initial deployment of a 95-m^2 heliostat is \$160 per m^2, plus a 10% contingency (\$176 per m^2).

Table E-15 — Heliostat Cost Estimate Comparison: Direct Capital Cost – Initial Deployment Scale from 148 to 95 m^2

	SunLab		Sargent & Lundy	
Heliostat Size	**Heliostat Cost**	**\$/m^2**	**Heliostat Cost**	**\$/m^2**
95 m^2 (scaled from 148 m^2 at a scaling factor of 0.8	\$14,214	\$150	\$15,168	\$160
148 m^2 (from Table E-14)	\$20,288	\$137	\$21,688	\$146

The major cost categories of the SunLab cost estimate for heliostats as compared to ADL are evaluated and discussed in Section E.5.

E.4.2 Technology Improvements

The annual heliostat field efficiency projections based on the SunLab model for each new deployment is shown in Table E-16. The annual heliostat field efficiency is the product of all the factors beneath it.

Table E-16 — Annual Heliostat Efficiency (SunLab vs. S&L)

	Solar One	Solar Two	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 220
	1988	**1999**	**2004**	**2006**	**2008**	**2012**	**2018**
Annual Heliostat Field Efficiency SunLab	58.1%	50.3%	56.0%	56.5%	56.3%	56.1%	57.0%
S&L	—	—	56.0%	56.5%	56.0%	55.2%	55.2%

	Solar One	Solar Two	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 220
	1988	1999	2004	2006	2008	2012	2018
Mirror Reflectivity							
SunLab	90.5%	90.7%	93.5%	94.0%	94.0%	94.5%	95.0%
S&L	—	—	93.5%	94.0%	94.0%	94.0%	94.0%
Field Optical Efficiency							
SunLab	69.0%	62.0%	64.6%	64.6%	63.7%	62.8%	62.8%
S&L	—	—	64.6%	64.6%	63.7%	62.8%	62.8%
Field Availability							
SunLab	99.0%	98.0%	98.5%	99.0%	99.5%	99.5%	99.5%
S&L	—	—	98.5%	99.0%	99.5%	99.5%	99.5%
Mirror Corrosion Avoidance							
SunLab	100.0%	97.0%	100.0%	100.0%	100.0%	100.0%	100.0%
S&L	—	—	100.0%	100.0%	100.0%	100.0%	100.0%
Mirror Cleanliness							
SunLab	95.0%	95.0%	95.0%	95.0%	95.5%	96.0%	97.0%
S&L	—	—	95.0%	95.0%	95.0	95.0%	95.0%
Field High Wind Outage							
SunLab	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%
S&L	—	—	99.0%	99.0%	99.0%	99.0%	99.0%

The increase in heliostat field efficiency is primarily based on increases in mirror reflectivity, field availability, and mirror cleanliness. The heliostat field efficiency at Solar Two was lower than at Solar One due to the re-use of equipment that had been abandoned for approximately 7 years, the use of second-hand PV trackers and uncurved mirrors, and a general lack of emphasis on the field because it had already been proven at Solar One (Reilly and Kolb 2001; Pacheco et al. 2002). The S&L evaluation of the efficiency for each deployment is shown in Section 5.6.

E.4.3 Economy of Scale

Cost improvements due to increasing the heliostat size goes from 95 m^2 to 148 m^2 (Solar 50 to Solar 100) are classed as scale improvements even though research, design, testing and manufacturing issues are associated with this change. The methodology to analyze this change is based on proven component scale-up techniques.

The scaling factor for going from the 95-m^2 heliostat to the 148-m^2 heliostat is shown in Table E-17. The cost projection for cost reduction due to scaling factor is reasonable since the scaling factor of 0.8 is more conservative than the industry standard of 0.7.

Table E-17 — Heliostat Scaling Factors - Direct Capital Cost Economy of Scale Change from 95 to 148 m^2 (Solar 100)

	SunLab			Sargent & Lundy		
Heliostat Size	**Heliostat Cost**	**$/m^2**	**Size**	**Heliostat Cost**	**$/m^2**	**Size**
95 m^2	$11,070	$117	95	$13,654	$144 **	95
148 m^2	$15,783	$107 *	148	$19,466	$132 ***	148
Scaling Factor	0.80			0.80		

* From Table E-11; SunLab cost estimate for Solar 100, 148-m^2 heliostat

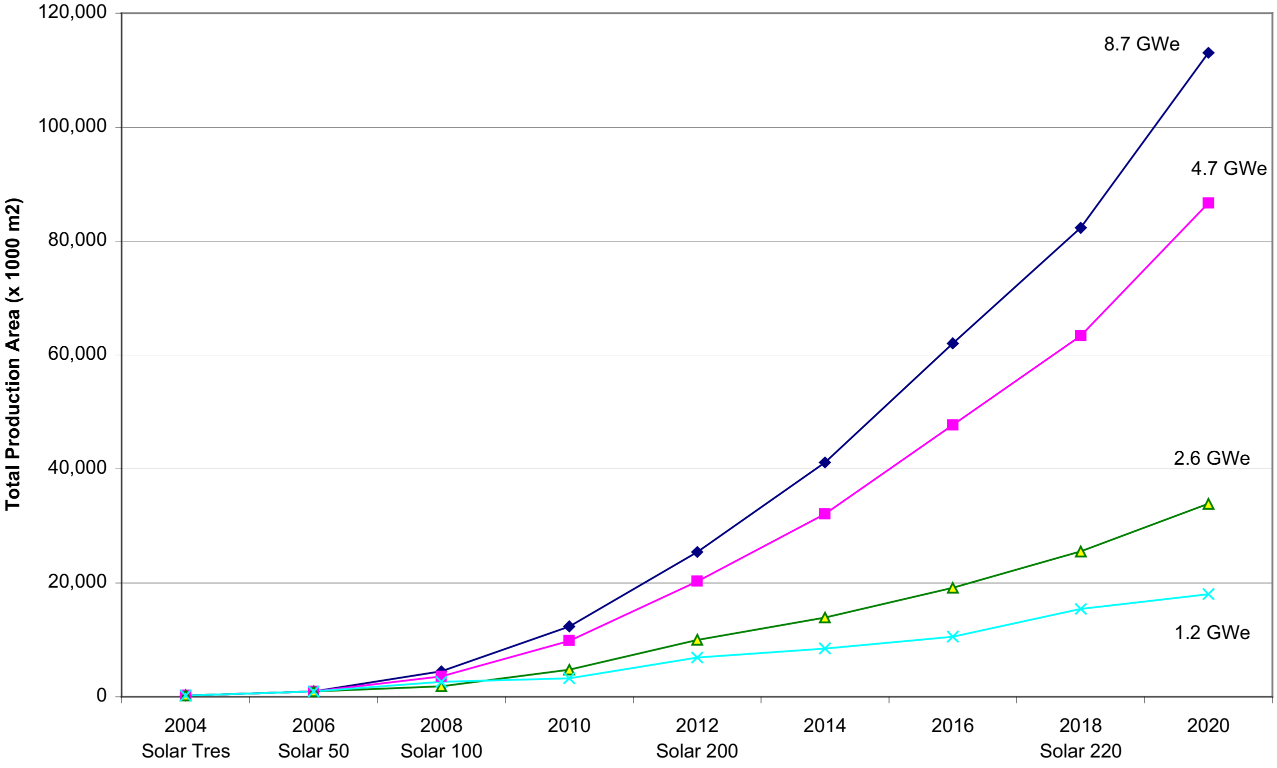
** Estimated cost of 95-m^2 heliostat based on progress ratio of 0.971 (see Table E-19) with deployment of 4.7 GWe

*** Calculated based on scale-up from 95 m^2 at $144 per m^2 to $132 per m^2

E.4.4 Estimate of Cost Reductions Due to Volume Production

This section explores cost reduction for heliostats, which is based on the number of heliostats being manufactured. As the number of heliostats increases, the cost will be reduced. The quantity of heliostats being manufactured is dependent on the deployment of plants. Deployment projections are discussed in Section 3. Heliostat production (m^2) based on a range of deployments (2.2 GW to 7.1 GW) is shown in Figure E-6.

Figure E-6 — Cumulative Heliostat Production (m^2) vs. Deployment Projections (installed GWe)



E.4.4.1 Progress Ratio and Determination of Heliostat Costs

Sargent & Lundy calculated the progress ratio for heliostats. Each cost component was evaluated and based on our detailed review of the SunLab and ADL detailed cost estimates (see Appendix E.5). The progress ratio ratios changes from the SunLab model are highlighted in Table E-18. For example, we did not concur with SunLab's cost improvement for installation costs as discussed in Section E.5; therefore, we adjusted the progress ratio to 1.0. The differences identified by S&L are as follows:

- Drives (azimuth) - Adjusted based on Section E.5.3.
- Structural Steel & Pedestal - SunLab projected a 5% weight improvement. There was no objective evidence; therefore, we projected a slight improvement for material quantity discounts (see Section E.5.7).
- Insulation and Field Wiring - SunLab projects a cost reduction for installation. Based on our experience, cost reductions are not as easily achieved for construction activities as manufacturing process.

The progress ratio for each heliostat cost activity was calculated based on the SunLab cost estimate. S&L estimated the final cost based on our evaluation and industry experience. The progress ratio was then calculated.

Table E-18 — Cost Improvements Due to Volume Production (148 m^2)

	Initial Production Volume	Final Production Volume
Annual Production, m^2	227,000	100,000,000
Doubling Factor	—	8.78

	SunLab Model			S&L Evaluation	
	Initial Cost	Final Cost	PR*	PR*	Cost
Mirrors	$1,924	$1,470	0.97	0.97	$1,472
Drive (azimuth)	$4,035	$1,670	0.90	0.94	$2,343
Drive (elevation)	$1,250	$990	0.97	0.97	$990
Structural Steel	$3,412	$2,930	0.98	0.99	$3,124
Pedestal	$1,705	$1,530	0.99	0.99	$1,561
Other	$770	$700	0.99	0.99	$700
Communications	$875	$630	0.96	0.96	$630
Labor	$800	$660	0.98	0.98	$660
Capital Equipment & Tooling	$863	$237	0.86	0.86	$237
Other Production Costs	$419	$298	0.96	0.96	$298
Total Fabrication Costs	$16,053	$11,114	0.96	—	$12,015
Corporate Overhead	$2,408	$1,667	0.96	—	$1,802
System Cost	$18,461	$12,782	0.96	0.96	$13,817
Installation	$950	$836	0.99	1.0	$950
Field Wiring	$877	$671	0.97	1.0	$877
Total Installed Cost	$20,288	$14,288	0.961	0.971	$16,739 **

	SunLab Model			S&L Evaluation	
	Initial Cost	Final Cost	PR*	PR*	Cost
Total Installed Cost per m^2	$137	$97	—	—	$113

* Calculated based on the initial and final cost estimate

** Includes adjustment is the difference between SunLab cost estimate and S&L: 7% as shown in Table E-14

The SunLab cost estimate of cost improvement was based on a final production of 100,000,000 m^2. The first deployment with 148-m^2 heliostats is Solar 100, which requires a collector field of 5,239,500 m^2 for each plant. The cost projection for going from 227,000 m^2 to 5,239,000 m^2 is shown in Table E-19.

Table E-19 — Final Cost for First Deployment of 148-m^2 Heliostats

148 m^2 – S&L	Initial	Final	Doubling Factor	PR
Volume, m^2	227,000	100,000,000	8.78	0.971
Total Cost, $/m^2	$146*	$113	—	—
Volume, m^2	227,000	5,239,500	4.53	0.971
Total Cost, $/m^2	$146*	$128	—	—

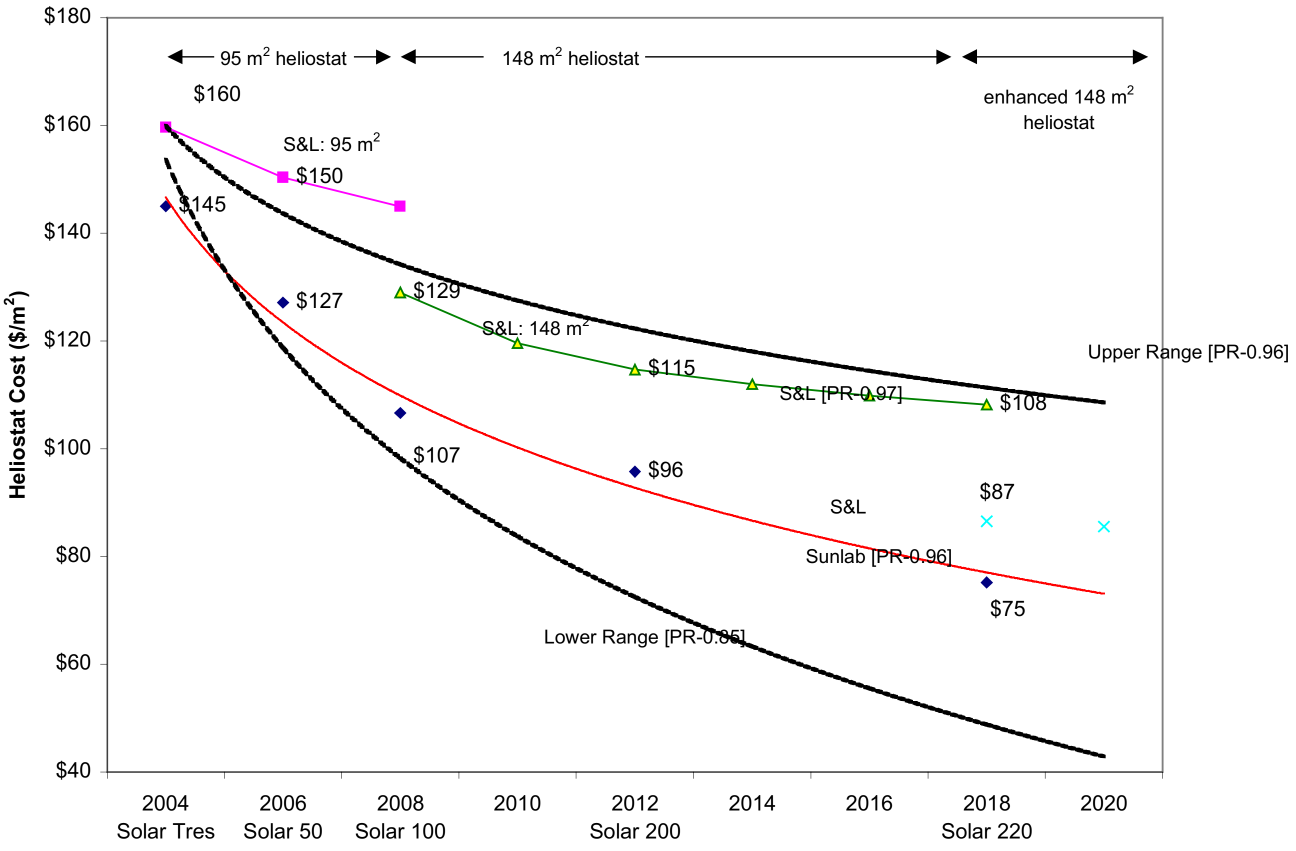
* From Table E-18 calculated based on progress ratio of 0.971 for volume of 5,239,500 m^2

E.4.5 Cost Comparisons

The comparison of heliostat cost improvements from 2004 to 2020 for a cumulative deployment of 8.7 GWe is shown in Figure E-7. The range of progress ratios used for the comparison by S&L is between 0.85 and 0.96. Various studies on learning curves from actual data suggest that a progress ratio of 0.82 has been observed for photovoltaics (PV) and 0.82 for development of wind energy during early deployment (1980 to 1995). The higher end of the range is from the Enermodal study for the World Bank, which identified a PV of 0.96 and the Wind Learning Rates compiled by Kobos for development of wind plants. (See Section B.6 for additional discussion.)

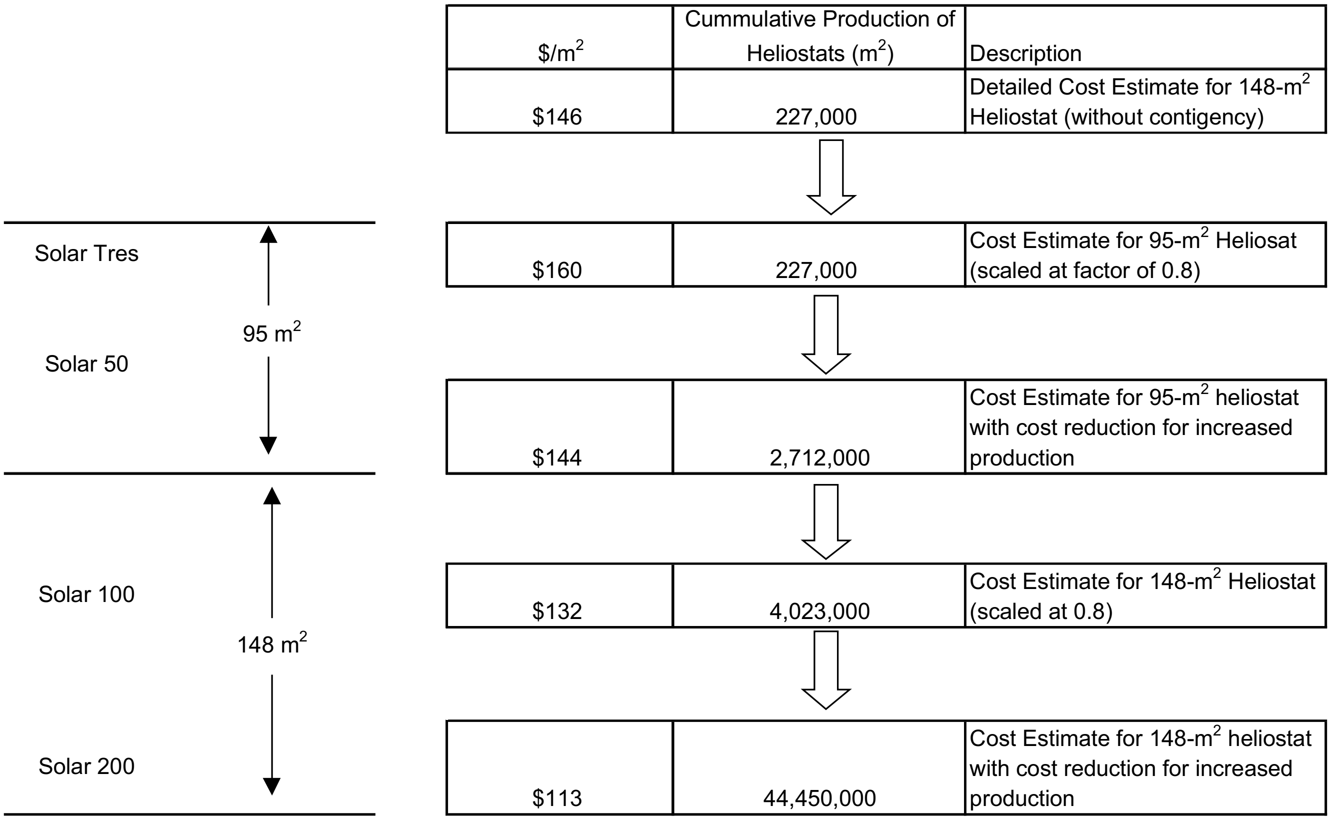
The progress ratio calculated for the S&L base case is 0.97 and 0.96 for 95-m^2 heliostats and 0.93 for 148-m^2 heliostats. The average progress ratio calculated for SunLab is 0.93. These values fall within the range of 0.85 to 0.96, as shown in Figure E-7.

Figure E-7 — Heliostat Cost Improvements (8.7 GWe)



Sargent & Lundy estimated heliostat costs based on a detailed review of the SunLab and ADL cost estimates. Cost reductions were then calculated as shown in Figure E-8.

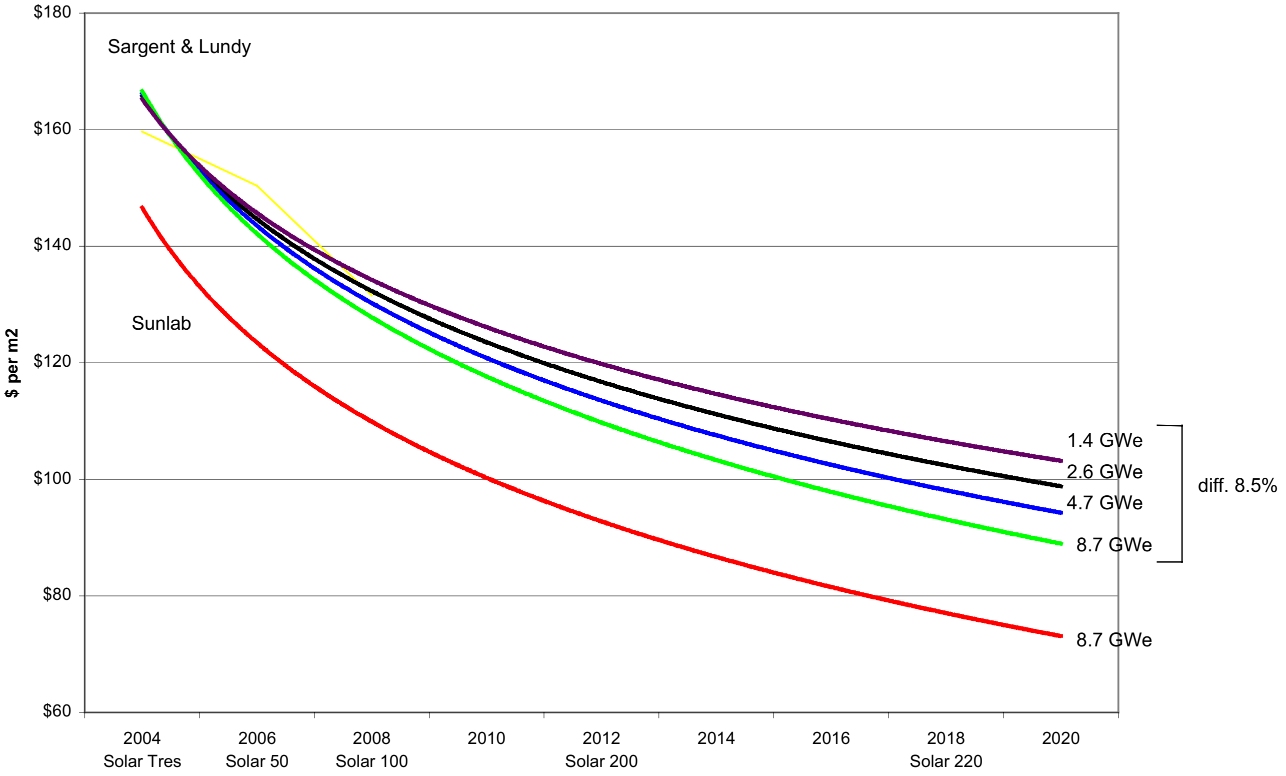
Figure E-8 — S&L Cost Estimate of Heliostats (Solar Tres to Solar 200)



$/m^2	Cummulative Production of Heliostats (m^2)	Description
$146	227,000	Detailed Cost Estimate for 148-m^2 Heliostat (without contigency)
$160	227,000	Cost Estimate for 95-m^2 Heliosat (scaled at factor of 0.8)
$144	2,712,000	Cost Estimate for 95-m^2 heliostat with cost reduction for increased production
$132	4,023,000	Cost Estimate for 148-m^2 Heliostat (scaled at 0.8)
$113	44,450,000	Cost Estimate for 148-m^2 heliostat with cost reduction for increased production

The comparison between S&L and SunLab collector field costs is based on a maximum deployment: SunLab at 8.7 GWe and S&L at 2.6 GWe. Heliostat costs for a range of deployment were calculated by S&L as shown in Figure E-9. The impact on the heliostat cost between 1.4 GWe and 4.7 GWe is about 6% for Solar 100 (2008), and 8.5% for Solar 220 (2018).

Figure E-9 — Heliostat Cost per m^2 versus Deployment



E.4.6 Cost Improvements

Cost improvements for heliostats are evaluated against three categories: technical (efficiency and design optimization), economy of scale and volume production. The cost reductions determined by S&L for the heliostat are an average of 30% due to technical improvements, 19% for scale-up, and 51% for volume production. The cost improvements for heliostats based on each change in plant size are shown in Section E.4.7.

The methodology of determining the cost breakout for heliostats is shown in Section E.4.7. The three categories were reviewed, and S&L assigned a percentage for each cost component. The total cost breakdown for the heliostat was then calculated based on the weighted average of the cost contribution of each component to the total cost.

E.4.7 Heliostat Cost Improvement Breakout by Category

The heliostat cost improvement is summarized in the following table.

Cost Improvement Summary

	Solar Two to Solar Tres	Solar Tres to Solar 50	Solar 50 to Solar 100	Solar 100 to Solar 200	Solar 200 to Solar 220	Average
Technical	26%	11%	35%	5%	72%	29.8%
Scaling	37%	0%	57%	0%	0%	18.6%
Volume	37%	89%	8%	95%	28%	51.4%

**Table E-20 — Solar Two to Solar Tres:
Heliostat Cost Improvement Breakout by Category**

Component	Percent of Total Cost	Technical	Scaling	Volume Production	Basis
Mirrors	8.6%			100%	The cost improvements are due to volume productions
Drive (azimuth)	45.0%	50%	50%	0%	The design is based on enhancement of a proven design. There will be technical improvements. The scaling factor is based on increasing the drive (48 m^2 to 95 m^2)
Drive (elevation)	4.9%	50%	50%	0%	The design is based on enhancement of a proven design. There will be technical improvements. The scaling factor is based on increasing the drive (48 m^2 to 95 m^2)
Structural Steel	9.2%	0%	50%	50%	Cost improvement is based on purchasing large quantities of commercially available steel shapes and the scaling factor for a larger structure (48 m^2 to 95 m^2)
Pedestal	3.3%	0%	50%	50%	Cost improvement is based on purchasing large quantities of commercially available steel shapes and the scaling factor for a larger structure (48 m^2 to 95 m^2)
Other	1.3%	0%	50%	50%	Cost improvement based on scaling factor (48 m^2 to 95 m^2) and volume production.
Communications	4.7%	20%	0%	80%	There will be technical improvements from operating experience and better production based on learning curve but the majority of the cost improvement will come from volume production.

Component	Percent of Total Cost	Technical	Scaling	Volume Production	Basis
Labor	2.7%	0%	50%	50%	Cost improvement is based on scaling factor (48 m^2 to 95 m^2) and volume production.
Capital Equipment & Tooling	11.9%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Other Production Costs	2.3%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Installation	2.2%	0%	50%	50%	Cost improvement is based on scaling factor (48 m^2 to 95 m^2) and volume production.
Field Wiring	3.9%	0%	50%	50%	Cost improvement is based on scaling factor (48 m^2 to 95 m^2) and volume production.
Total (Weighted Average)	—	26%	37%	37%	

Table E-21 — Solar Tres to Solar 50:
Heliostat Cost Improvement Breakout by Category

Component	Percent of Total Cost	Technical	Scaling	Volume Production	Basis
Mirrors	8.6%	0%	0%	100%	The cost improvements are due to volume productions
Drive (azimuth)	45.0%	20%	0%	80%	The design is based on enhancement of a proven design. There will be technical improvements but the majority of improvements will come from volume production.
Drive (elevation)	4.9%	20%	0%	80%	The design is based on enhancement of a proven design. There will be technical improvements but the majority of the cost improvements will come from volume production.
Structural Steel	9.2%	0%	0%	100%	Cost improvement is based on purchasing large quantities of commercially available steel shapes.
Pedestal	3.3%	0%	0%	100%	Cost improvement is based on purchasing large quantities of commercially available steel shapes
Other	1.3%	0%	0%	100%	Cost improvement based on volume production.
Communications	4.7%	20%	0%	80%	There will be technical improvements from operating experience and better production based on learning curve but the majority of the cost improvement will come from volume production.
Labor	2.7%	0%	0%	100%	All cost improvement is based on volume production.
Capital Equipment & Tooling	11.9%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Other Production Costs	2.3%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Installation	2.2%	0%	0%	100%	All cost improvement is based on volume production
Field Wiring	3.9%	0%	0%	100%	All cost improvement is based on volume production
Total (Weighted Average)	—	11%	0%	89%	

Table E-22 — Solar 50 to Solar 100: Heliostat Cost Improvement Breakout by Category

Component	Percent of Total Cost	Technical	Scaling	Volume Production	Basis
Mirrors	8.6%	100%	0%	0%	The cost improvements are due to installation of thin mirrors to increase reflectivity
Drive (azimuth)	45.0%	50%	50%	0%	The design is based on enhancement of a proven design. There will be technical improvements. The scaling factor is based on increasing the drive (95 m^2 to 148 m^2)
Drive (elevation)	4.9%	50%	50%	0%	The design is based on enhancement of a proven design. There will be technical improvements. The scaling factor is based on increasing the drive (95 m^2 to 148 m^2)
Structural Steel	9.2%	20%	80%	0%	Cost improvement is based on design changes to accommodate the thin mirrors and the scaling factor for a larger structure (95 m^2 to 148 m^2)
Pedestal	3.3%	20%	80%	0%	Cost improvement is based on design changes to accommodate the thin mirrors and the scaling factor for a larger structure (95 m^2 to 148 m^2)
Other	1.3%	0%	100%	0%	Cost improvement based on scaling factor (95 m^2 to 148 m^2) and volume production.
Communications	4.7%	20%	0%	80%	There will be technical improvements from operating experience and better production based on learning curve but the majority of the cost improvement will come from volume production.
Labor	2.7%	0%	100%	0%	Cost improvement is based on scaling factor (95 m^2 to 148 m^2)
Capital Equipment & Tooling	11.9%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Other Production Costs	2.3%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Installation	2.2%	0%	100%	0%	Cost improvement is based on scaling factor (95 m^2 to 148 m^2)
Field Wiring	3.9%	0%	100%	0%	Cost improvement is based on scaling factor (95 m^2 to 148 m^2)
Total (Weighted Average)	—	35%	57%	8%	

Table E-23 — Solar 100 to Solar 200: Heliostat Cost Improvement Breakout by Category

Component	**Percent of Total Cost**	**Technical**	**Scaling**	**Volume Production**	**Basis**
Mirrors	8.6%	0%	0%	100%	The cost improvements are due to volume productions
Drive (azimuth)	45.0%	10%	0%	90%	The design is based on enhancement of a proven design. There will be technical improvements but the majority of improvements will come from volume production.
Drive (elevation)	4.9%	10%	0%	90%	The design is based on enhancement of a proven design. There will be technical improvements but the majority of the cost improvements will come from volume production.
Structural Steel	9.2%	0%	0%	100%	Cost improvement is based on purchasing large quantities of commercially available steel shapes.
Pedestal	3.3%	0%	0%	100%	Cost improvement is based on purchasing large quantities of commercially available steel shapes
Other	1.3%	0%	0%	100%	Cost improvement based on volume production.
Communications	4.7%	10%	0%	90%	There will be technical improvements from operating experience and better production based on learning curve but the majority of the cost improvement will come from volume production.
Labor	2.7%	0%	0%	100%	All cost improvement is based on volume production.
Capital Equipment & Tooling	11.9%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Other Production Costs	2.3%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Installation	2.2%	0%	0%	100%	All cost improvement is based on volume production
Field Wiring	3.9%	0%	0%	100%	All cost improvement is based on volume production
Total (Weighted Average)	—	5%	0%	95%	

Table E-24 — Solar 200 to Solar 220:
Heliostat Cost Improvement Breakout by Category

Component	Percent of Total Cost	Technical	Scaling	Volume Production	Basis
Mirrors	8.6%	100%	0%	0%	The cost improvements are technical advances in developing an enhanced heliostat
Drive (azimuth)	45.0%	100%	0%	0%	The cost improvements are technical advances in developing an enhanced heliostat
Drive (elevation)	4.9%	100%	0%	0%	The cost improvements are technical advances in developing an enhanced heliostat
Structural Steel	9.2%	100%	0%	0%	The cost improvements are technical advances in developing an enhanced heliostat
Pedestal	3.3%	100%	0%	0%	The cost improvements are technical advances in developing an enhanced heliostat
Other	1.3%	0%	0%	100%	Cost improvement based on volume production.
Communications	4.7%	10%	0%	90%	There will be technical improvements from operating experience and better production based on learning curve but the majority of the cost improvement will come from volume production.
Labor	2.7%	0%	0%	100%	All cost improvement is based on volume production.
Capital Equipment & Tooling	11.9%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Other Production Costs	2.3%	0%	0%	100%	Cost improvement is based on better production techniques and the majority on volume production
Installation	2.2%	0%	0%	100%	All cost improvement is based on volume production
Field Wiring	3.9%	0%	0%	100%	All cost improvement is based on volume production
Total (Weighted Average)	—	72%	0%	28%	

E.5 POWER TOWER HELIOSTAT COST EVALUATION

E.5.1 Mirrors

Mirror costs in the SunLab model are essentially the same as ADL for one plant deployment as shown in Table E-25. The mirror cost estimate has a medium to high degree of accuracy based on vendor supplied pricing quotes. The mid point of the range of quotes \$1.00 to \$1.50 per ft^2 was used by ADL. The cost improvement estimate based on quantity purchasing is a reasonable. The key difference between normal glass and that used for heliostats is that normal glass has iron whereas solar glass uses low iron. The manufacturers have the capability to manufacturer the glass, but the higher cost is due to a premium for shutting down production of normal glass and resetting for a production run of solar glass. Higher quantity of demand will increase the production run time for solar applications and reduce the premium cost. The SunLab estimate for cost improvement is \$0.95 per ft^2 which is conservative since it is about twice the cost of normal glass of \$0.47 per ft^2 estimated by Head West Inc. (Arthur D. Little 2001), which still allows for \$0.48 per ft^2 premium for manufacturing production runs (see Table E-25).

Glass mirrors are expensive and heavy. Research in alternate mirrors is required to reduce costs. The new mirrors must have the same or better optical quality and have the same durability as glass mirrors. Glass mirrors have proven at SEGS and the Solar demonstration plants have shown that with proper design there has been no long-term degradation of the reflective quality. The alternate glass must be able to withstand continuous washing without damaging the reflective surface. The SunLab model does not assume a technology change to lighter glass until Solar 200.

Table E-25 — Mirrors: Cost Comparison between SunLab and ADL

Mirrors	**SunLab**		**AD Little**	
	Cost	**Production Volume (cumulative)**	**Cost**	**Production Volume (annual)**
Base Plant	\$1.21 per ft^2 (\$13.02 per m^2)	227,000 m^2 (1,534 units)	\$1.24 per ft^2 (\$13.35 per m^2)	440,000 m^2 (3,000 units)
Production Cost Improvement	\$0.95 per ft^2 (\$10.20 per m^2)	100,000,000 m^2 (675,676 units)	Not Studied	4,440,000 m^2 (30,000 units)
Description	Single sheet mirror construction. There are four mirror assemblies with 25 4' x 4' (1.49 m^2) mirrors for a total of 100 mirrors.			

E.5.2 Mirror Assembly

The mirror assembly is not a complex structure. The cross members and hat sections are commercially available and are assembled by welding. There are four mirror assemblies with 25 4’ x 4’ (1.49 m^2) mirrors for a total of 100 mirrors. The mirrors, which are commercially available low lead reflective glass, are attached with RTV. The only risk is the integrity of the bond between the mirrors and metal. This risk is low; these are the same mirrors as SEGS and the RTV is upgraded based on improvements developed to solve wind damage.

The carousel assembly system for mirrors has been used in the construction of about 13,000 mirror modules for 95 m^2 trackers. The assembly of mirror will take place in a 10,000-ft^2 building at or near the plant site. The details of the facility, equipment, process sequence, man-loading and time sequence is provided the SolMaT study done by Solar Kinetics, Inc. (1996) for 148 m^2. Solar Kinetics has independently documented their approach in the “Mirror Module Assembly Plan.” The results of the study are summarized below:

- A list of major equipment required to build mirror modules is provided but there is no cost estimate. ATS stated that the $1 million estimate used by SunLab was reasonable.
- Mirror module assembly estimate is 17 man-hours, which includes 10% fringe time and 20% down time. The estimate is based on 1,000 heliostats per year with two 6-day shifts working for 32 weeks (5.5 per shift: 3.5 workers, 1 supervisor, and 1 QA inspector. The SunLab estimate is 24 man-hours.
- The rack assemble consists of the pedestal, torque tube assembly and rack. The ‘rack’ is everything above the pedestal. The materials are commercially available and assembled by welding.

E.5.3 Drives

The estimated cost of the drive and cost improvement from production volume are essentially the same as the ADL study as shown in Table E-26. ADL’s conclusion is based on discussions with vendors, specifically Peerless Winsmith and Hub City. ADL identified in their report that improvement in drive costs “are possible at higher volumes because this amount of business can justify a dedicated production facility.” ADL assumptions were $6,000 per unit for 1,000 annual production $4,000 per unit for 3,000 annual production, and $3,000 per unit for 30,000 annual production. The difference between the costs is that the SunLab cost estimate included a rotary azimuth drive and elevation drive whereas the ADL cost estimate included a dual axis drive.

Table E-26 — Drives: Cost Comparison between SunLab and ADL

Drives	SunLab		AD Little	
	Cost	Production Volume (cumulative)	Cost	Production Volume (annual)
Base Plant	\$5,885	227,000 m^2 (1,534 units)	\$4,000	440,000 m^2 (3,000 units)
Production Cost Improvement	\$3,030	100,000,000 m^2 (675,676 units)	\$3,000	4,440,000 m^2 (30,000 units)
Description	The current technology solution of ball screw, worm gear, or hydraulic drives for the azimuth and elevation drives. SunLab drive consists of a lower cost azimuth drive developed by Peerless Winsmith and a separate elevation drive. The ADL cost study included a single axis drive.			

The next generation drive (Solar Tres) design is a planocentric azimuth drive coupled with a scissor joint and ball screw actuator. NREL contracted with Peerless-Winsmith in 1996 to define and develop the manufacturing procedures and costs for a dual axis drive system with focus on more accurate cost information (DFMA Workshop, contract ACG-5-15209-01). Peerless-Winsmith has designed this lower cost drive for Sandia, and therefore, DOE owns the rights to the drive. The drives are still in the development stage; about ten drives have been built. Peerless-Winsmith has a contract presently to provide detailed price projections for 1,500 units. Winsmith developed new cost data for the low cost azimuth solar drive in October 1999 "Enhanced Azimuth Solar Drive Project for Sandia National Laboratories," Contract Number BF-0031. The azimuth solar drive reflects the latest changes and improvements of the azimuth drive design, including o-ring seals and replacing the power transfer chain with eccentric drive shafts. The cost data were based on a detailed material list of parts, labor, and cost for pattern & tooling and cost improvements up to 500 units (see Table E-27). These costs are provided by the manufacturer based on detailed design and therefore have a fairly high accuracy. Winsmith stated, "The project team feels that given even higher quantities, further cost improvements can be obtained with higher tooling and equipment outlays."

Table E-27 — Peerless Cost Estimates for Drives

	Cost for Ten Units			Cost for 500 Units		
	Unit Cost	Pattern & Tooling	Total Cost	Unit Cost	Pattern & Tooling	Total Cost
Worm & planocentric	$5,331	$14,595/10 = $1,460	$6,791	$4,064	$44,385/500 = $89	$4,153
Planetary & planocentric	$5,377	$14,595/10 = $1,460	$6,797	$4,035	$44,385/500 = $89	$4,124

Peerless-Winsmith designed, developed, and tested an azimuth drive in 1987 to handle loads for the 148-m^2 heliostat. The drive has been used for various applications, including a few prototype trackers, a prototype ATS heliostat located at Sandia, and a few units for testing. The estimated cost (see Table E-28) for the next generation heliostat drive (Solar Tres) is reasonable based on the following:

- Peerless cost estimate for the 148-m^2 azimuth drive (500 units) is $4,150 per unit. This is for a two-stage azimuth drive only, not for elevation drive.
- SunLab cost estimate for the 148-m^2 azimuth drive (1,534 units) is $4,035 per unit.
- Comparison of the SunLab cost estimate for 95 m^2 and 148 m^2 indicates a scaling factor of 0.62 based on weight (see Table E-28). This is within the range of an acceptable assumption.
- Nook industries quoted a cost of $805 for 500 ball screws (elevation drives) for the 95-m^2 heliostats.

Table E-28 — Economy of Scale between the 95-m^2 and 148-m^2 Heliostat Drives

Heliostat Size (m^2)	**95**	**148**
Heliostat Weight	10,890	16,490
Rotary azimuth drive	$3,400	$4,035
Elevation drive pivot structure	$400	$600
Elevation drive actuator	$750	$1,250
Total Drive Cost	$4,550	$5,885
Scaling factor based on weight	—	0.62

E.5.4 Control and Communications

The SunLab cost estimate for control and communications is shown in Table E-29. ADL did not include the cost of control & communication in their estimate.

Table E-29 — Control & Communications Cost

Control & Communication	SunLab		AD Little	
	Cost	Production Volume	Cost	Production Volume
Base Plant	$875	227,000 m^2 (1,534 units)	Not included	—
Production Cost Improvement	$640	100,000,000 m^2 (675,676 units)	—	—

The SunLab estimate is based on the following:

- Logic Board & Controller: base is $300/production improvement is $130.
- Encoders, wiring & enclosure – base is $305 / production is $260.
- Two DC motors – base is $270 / production is $250.

The cost improvements projected by SunLab are reasonable. The largest contributor to the cost improvement is the logic board & controller. The electronics business has shown significant cost improvements with increases in production (computer technology is an excellent example). The cost improvement has a progress ratio of 0.88, which is a conservative assumption. Average module technologies based on electronics are 0.80 (Neij 1997). The other cost improvements are within the range of expected cost improvements: encoders, wiring & enclosure – progress ratio of 0.98 and DC motors – progress ratio of 0.99.

E.5.5 Production (Shop) Fabrication

The cost comparison for production fabrication costs is shown in Table E-30.

Table E-30 — Production Fabrication Cost Comparison between SunLab and ADL

Shop Fabrication	SunLab		AD Little	
	Cost	Production Volume	Cost	Production Volume
Base Plant	$800	227,000 m^2 (1,534 units)	$1,552	—
Production Cost Improvement	$345	100,000,000 m^2 (675,676 units)	—	—

The SunLab cost estimate is based on the following assumptions shown in Table E-31:

Table E-31 — SunLab Assumptions

Activity	Base Case	Production Volume
Mirror Support	8 mhrs	4.9 mhrs
Mirror Modules	24 mhrs	8.9 mhrs
Total Manufacturing	32 mhrs	14 mhrs
Labor Rate (including benefits)	$25	$25

The ADL cost estimate is based on the following assumptions:

- Labor cost (direct and indirect): $1,552
- Labor Rate (including benefits): Assembly - $12 per hour; Skilled Labor - $18 per hour; Average $15 per hour.
- Total manufacturing (direct and indirect): 103 mhrs ($1,552/$15)

The Solar Kinetics, Inc. cost estimate is based on the following assumptions:

- A list of major equipment required to build mirror modules is provided but there is no cost estimate.
- Heliostat assembly estimate is 18 man-hours (not including painting, final assembly and checkout, which SKI estimates at 1+3.3+1=5.3 hours or 23 hours total), which includes 10% fringe time and 20% down time. The estimate is based on 1,000 heliostats per year with two 6-day shifts working for 32 weeks (6 per shift: 5 workers and 1 supervisor).

SunLab projection for the base case is reasonable based on the following observations:

- The estimate for assembly hours (18 hrs) studied by Solar Kinetics is less than SunLab.
- The ADL study can not be used as a comparison since it includes direct and indirect costs.
- SunLab model is based on setting up the production facility at the site. ADL study is based on setting up an independent production facility.

SunLab projection for volume production cost improvements is optimistic based on the following observations:

- The Solar Kinetic estimate of 18 mnhrs is based on 1,000 heliostats per year. It is not likely that there will be a significant improvement in manhours as a result of increasing production by a factor of 6.

E.5.6 Installation

The installation cost estimate and comparison between SunLab and ADL is shown in Table E-32.

Table E-32 — Installation Costs Comparison between SunLab and ADL

Installation & Checkout	SunLab		AD Little	
	Cost	Production Volume (cumulative)	Cost	Production Volume
Base Plant	$1,827	227,000 m^2 (1,534 units)	$1,427	—
Production Cost Improvement	$1,167	100,000,000 m^2 (675,676 units)	—	—

The SunLab cost estimate is based on the following assumptions shown in Table E-33:

Table E-33 — SunLab Cost Assumptions

Activity	Base Case	Production Volume
Foundation	$200	$153
Installation		
Pedestal	3 mhrs	2.3 mhrs
Paint	2 mhrs	1.5 mhrs
Final Assembly	24 mhrs	8.9 mhrs

Activity	Base Case	Production Volume
Checkout/Startup	1 mhr	1 mhr
Total Installation	30 mhrs	15 mhrs
Labor Rate (including benefits)	$25	$25
Field Wiring	$877	$671

The ADL study was based on discussions with construction companies and their 2001 CostWorks analysis. The assumptions are as follows:

- Installation: 4 hours with 3 workers = 12 man-hours
- Labor Rate (including benefits): $15
- Vendor quote to drill hole, place pedestal and concrete: $800
- Cost of aerial lift: $447 (based on about 4 lifts a day at 5 ton crane rental of $1,738 per day)

Note that the ADL study for installation cost does not add up correctly: (12 mhrs x $15 = $180) plus ($800) plus ($447) equals $1,427 not $2,072

The SunLab cost projection for the base case is lower than expected based on the following observations:

- Comparison of the ADL and the SunLab cost estimates corrected for labor rate and field wiring indicate that ADL is higher (ADL is $1,622 and SunLab is $950)
- The ADL cost estimate is based on vendor quotes

The SunLab cost projection for volume is optimistic based on the following observations. S&L adjusted their cost estimate to compensate for these.

- The main cost improvement is the final assembly from 24 man-hours to 8.9 man-hours, which is not realistic. Cost improvements would only be expected with improvement in assembly techniques, equipment, and tools and there is really not much to improve for the installation process.
- Man-hour improvements are not as easily achieved for a construction activity as for a manufacturing process.

E.5.7 Structural Steel, Pedestal and Other

The SunLab cost projection for the base case (see Table E-34) is reasonable based on the following observations:

- There is a difference of $289 per unit for material costs of the structural steel, pedestal and other (see Table E-34). The difference is a result of two different cost estimating methods and is not significant (1.8% of total fabrication cost).
- The estimate is based on actual design drawings and material costs

Table E-34 — Structural Steel and Pedestal Cost Comparison

Structural Steel, Pedestal, & Other	SunLab Base Plant	AD Little Base Plant
Structural Steel	$3,412	$2,122
Pedestal	$1,705	$1,330
Other	$770	$2,146
Total	$5,887	$5,598

The SunLab cost projection for volume is optimistic based on the following observations. S&L adjusted their cost estimate to compensate for this.

- SunLab projects a 5% weight improvement in the structural steel and pedestal based on a more rigorous design and analysis. The cost improvement is from $138 per m^2 to $127 per m^2. There was no objective information to evaluate this cost improvement.

E.5.8 Overhead and Profit

Table E-35 — Overhead and Profit

	SunLab		AD Little	
	Base Plant	Production Cost Improvement	Base Plant	Production Cost Improvement
Overhead and Profit	15%	15%	25%	N/A
Fixed Costs	$5.83 per unit	$1.60 per unit	Included in Overhead and Profit	—

The financial assumptions for ADL are shown below:

Table E-36 — Financial Assumptions for ADL

Equipment Depreciation	7 years
Cost of Capital	15%
Sales & Distribution	4% of sales
General & Administrative	8% of sales
R&D	0% of sales
Insurance	1% of sales
Federal Taxes	3% of sales
State Taxes	1% of sales
Net Profit	8% of sales
Corporate Overhead	25% of sales

The SunLab cost estimate is low based on the ADL cost estimate. S&L adjusted their estimate to compensate for this.

E.5.9 Capital Equipment and Tooling

Table E-37 — Capital Equipment and Tooling

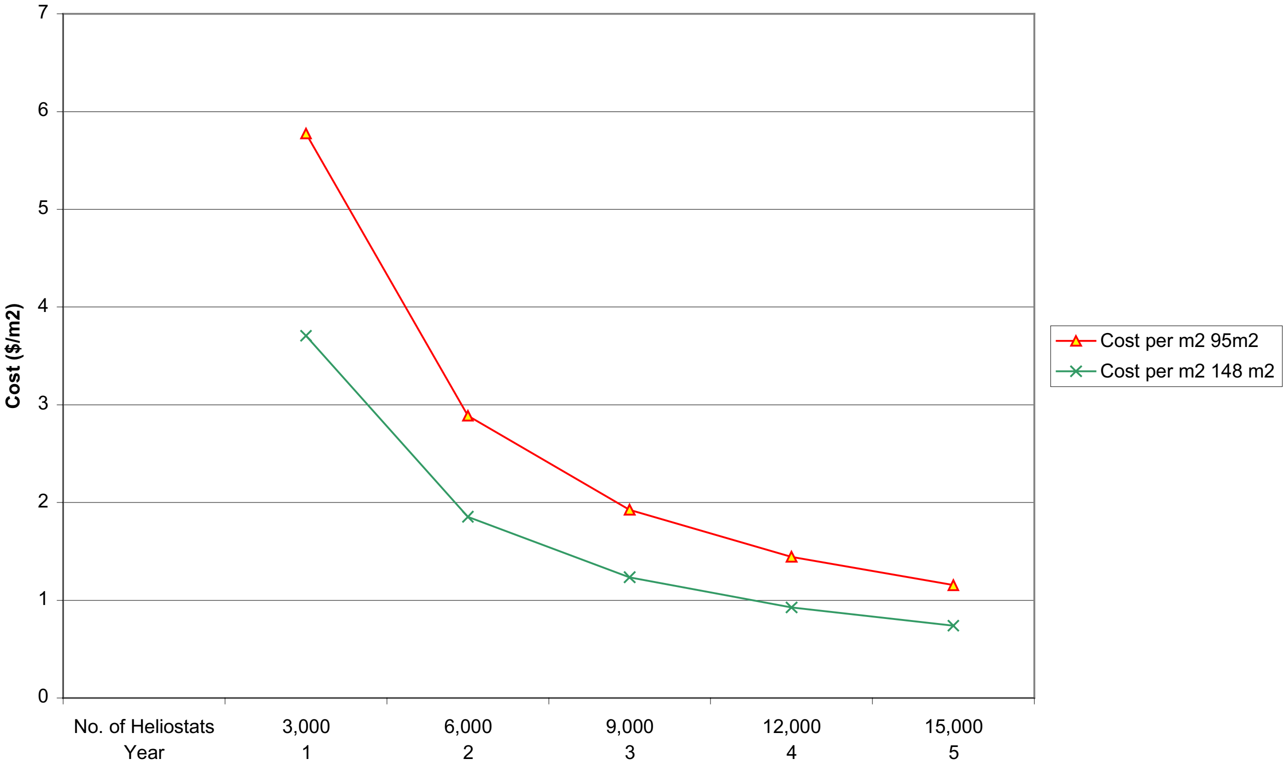
Capital Equipment and Tooling	SunLab Base Plant	AD Little Base Plant
Production	1,534	3,000
Engineering Design	$259,000	—
Manufacturing Facilities and Tooling	$800,000	—
Equipment Lease	$200,000	—
Field Computer and BCS System	$150,000	—
Total	$1,400,000	$903,000
Cost per Heliostat	$912.65	$301

The SunLab cost estimate is slightly less than the value shown in Table E-37. S&L adjusted their cost estimate to compensate for this.

The difference is attributed to ADL basing their cost on a supplier setting up a manufacturing facility whereas SunLab's estimate is based on a local assembly shop associated with the construction project.

Cost improvements based on volume production are shown in Figure E-10.

Figure E-10 —Heliostat Capital Cost and Equipment Cost Reductions



E.6 ELECTRICAL POWER BLOCK

E.6.1 Capital Cost

Sargent & Lundy estimated the cost for the power block based on the SOAPP model,[*] compared it to our internal database, and then adjusted the output for labor and productivity rates in the Southwest. The results of

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[*] EPRI SOAPP is a fully integrated program for technology evaluation, conceptual design, costing, and financial analysis of combustion-turbine-based power plants for project and proposal development. SOAPP-CT integrates process design, costing, and financial analysis of combustion turbine simple- and combined-cycle power plants, including cogeneration. Sargent & Lundy developed SOAPP under contract to EPRI.

our review are shown in Table E-38 and Figure E-11. The power block costs include the steam turbine and generator, steam turbine and generator auxiliaries, feedwater, and condensate systems.

Table E-38 — Capital Cost of Electrical Power Block

		Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Power Block	MWe	—	13.5	50	100	200	220
SunLab	$M	—	$10.0	$24.5	$40.0	$64.0	$83.6
	$/kWe	—	$730	$490	$400	$320	$380
S&L	$M	—	$7.6	$18.6	$30.6	$46.2	$61.8
	$/kWe	—	$563	$373	$306	$231	$281

E.6.2 Technology Improvements

E.6.2.1 Efficiencies

The power block is a conventional Rankine-cycle steam turbine. The Rankine-cycle steam turbine is an established technology with future major improvements focusing on increased inlet steam pressure and temperature conditions to increase the cycle efficiency.

The steam cycle foundation is the Rankine cycle. As the inlet steam conditions (pressure and temperature) increase, the Rankine cycle efficiency increases. The near-term steam cycle efficiency from 34% to 40.3% is predicated on increasing the inlet steam temperature from 510°C to without reheat 540°C with reheat. The long-term increase to 42.8% for Solar 200 is based on 540°C steam inlet temperature. The net steam turbine efficiency. The increase from Solar 200 (42.8%) to Solar 220 (46.1%) is based on 640°C steam inlet temperature with an advanced double reheat turbine. The summary of steam turbine efficiency projections is shown in Table E-39.

Table E-39 – Turbine Projected Efficiencies

Design Details	Solar One	Solar Two	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 220
	1988	1999	2004	2006	2008	2012	2018
Plant output, net, MWe	10	10	13.7	50	100	200	220
Rankine Cycle							
Pressure, Bar	125	125	125	125	125	180	300
Live steam Temp, °C	510	510	540	540	540	540	640
Reheat #1 Temp, °C	—	—	540	540	540	540	640
Reheat #2 Temp, °C	—	—	—	—	—	540	640
Rankine Cycle Design Point Efficiency							
SunLab, %	32.0%	34.0%	40.3%	41.8%	42.3%	42.8%	46.1%
S&L, %	—	—	38.0%	40.6%	41.4%	42.8%	45.6%

The net steam turbine efficiency (gross efficiency minus the percentage of parasitic power consumption required for plant operation) is accounted for by calculation of the parasitic consumption separately. The near-term turbine efficiency was verified by S&L based on the ABB-Brown Boveri heat balances (HTGD 582395, Sheets 1-7) for SEGS IX, which show an efficiency of 37.7% (in LUZ International Limited 1990). The Rankine cycle efficiency gains for increasing the inlet steam temperature from 540°C to 640°C were verified by S&L by using General Electric STGPER software program (Version 4.08.00, January 2002). The results from the STGPER software for Solar 200 and Solar 220 were extrapolated to account for dual reheat turbines. The turbine efficiencies are summarized in Table E-39.

The type of heat transfer fluid (HTF) determines the operational temperature and thus the maximum power cycle efficiency that can be obtained. The HTF molten nitrate salt (60 wt % $NaNO_3$ and 40 wt % KNO_3) nitrate salt used in Solar Two demonstrated that steam temperatures of 540°C were achieved (Pacheco et al. 2002); for example, test no. 5 at full flow conditions measured actual HTF at 557°C and steam temperature at 542°C.

E.6.2.2 Discussion

There are no steam turbine technological risks in achieving the SunLab projected efficiencies. There are currently numerous steam turbines operating with steam inlet conditions over 250 bar pressure and 590°C temperature, with gross efficiencies over 44%.* The advance from Solar 200 to Solar 220 is based on current research on increasing the inlet steam pressure and temperature conditions. This increase in efficiency for steam turbines is technically feasible and should be available by 2018. The major issue will be the higher temperatures and impact on materials.

E.6.3 Economy of Scale

There are recognized scale-up cost reductions for the power block. Using the SOAPP software program and S&L's internal database, the scale-up factor was estimated for the increasing the power block from 13.5 MW to 200 MW, as depicted on Figure E-11. The S&L trend curve is expressed as:

$$Y = (1{,}275.8)\, x^{-0.3145}$$

Where:

Y = \$/kW

x = MWe

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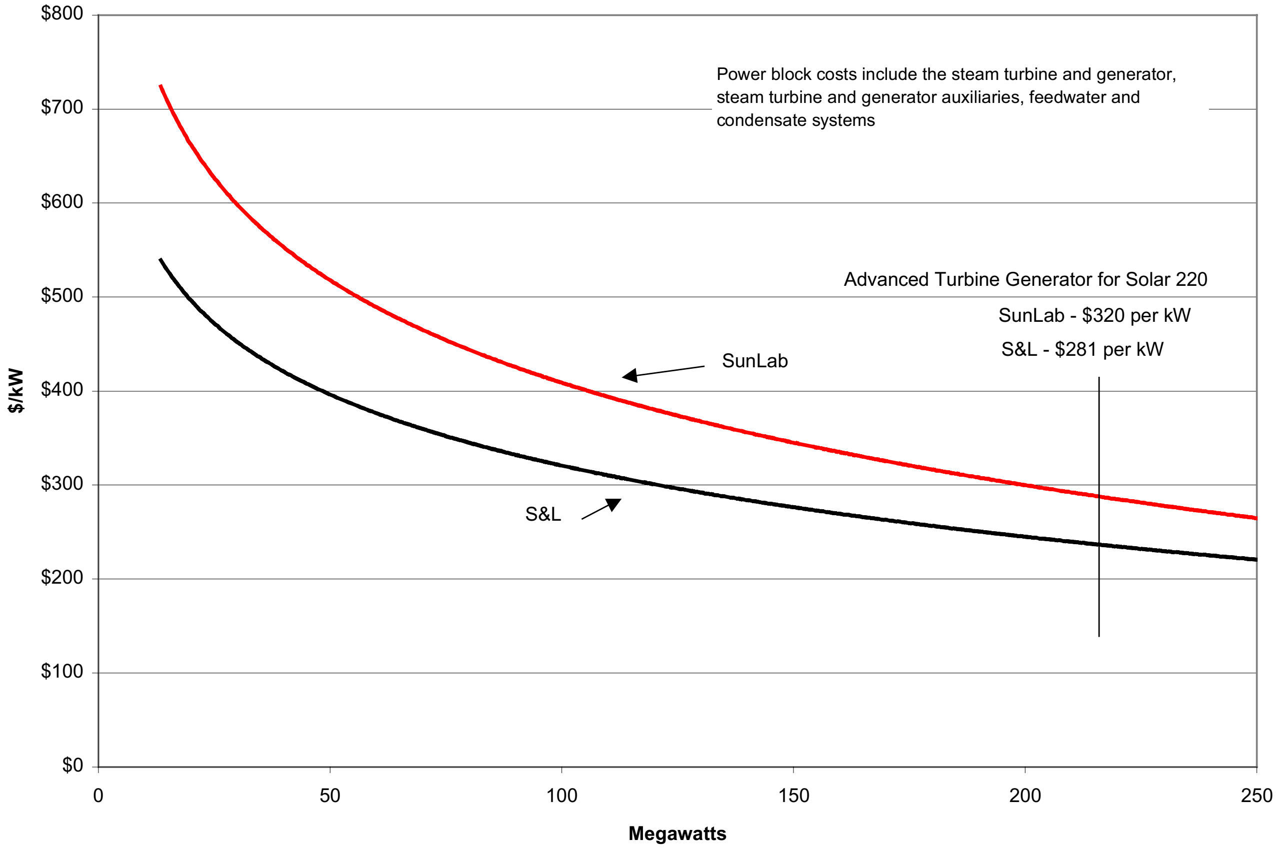
* Plant (commercial operation date): Nanaoota 1 (1995), Noshiro 2 (1995), Haramachi 1 (1997), Haramachi 2 (1998), Millmerran (2002), Matauura 2 (1997), Misumi 1 (1998), Tachibana Bay (2000), Bexback (2002), Lubeck (1995), Aledore 1 (2000), Nordjylland (1998). From *Power* (Swanekamp 2002).

Figure E-11 — Capital Cost of Electrical Power Block



However, since a single steam turbine is supplied with each tower plant, production volume is not a consideration for cost reduction.

E.6.4 Cost Improvements

Cost improvements were evaluated by S&L against three categories: technical (efficiency and design optimization), economy of scale, and volume production. The cost reductions determined by S&L for the electric power block is an average of 18% due to technical improvements, 82% for scale-up, and 0% for volume production. The cost improvements for the electric power block based on step changes in plant size and breakdown comparison is shown in Section 5.7.

E.7 RECEIVER

E.7.1 Capital Cost

Table E-40 — Capital Cost of Receiver

	Solar One	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
	1988	**1999**	**2004**	**2006**	**2008**	**2012**	**2018**
Net Plant Size – Thermal, MWt	46	42	120	380	700	1,400	1,400
Receiver System Capital Cost –SunLab, $M	$39.2	$9.1	$14.7	$23	$29.1	$39.4	$43.3
Receiver System Capital Cost –S&L (based on Boeing), $M	—	—	$16	$26	$34	$46	—
Receiver System Capital Cost, $/kWt	—	—	$133	$68	$49	$33	—

The SunLab cost estimate for the capital cost for receiver is lower than the latest Boeing cost estimate. The SunLab cost estimate should be adjusted to be in accordance with the latest detailed Boeing cost estimate. S&L determined that the Boeing cost estimate is reasonable based on the following:

- The cost estimate is based on actual costs from Solar Two, which adjustments to compensate for design improvements, manufacturing improvements, construction labor rates and escalation.
- The cost estimate is based on detailed design drawings and material take-offs (bottoms up cost estimate), which provides a higher degree of accuracy.
- Estimates for Solar 50, 100, and 200 receivers were developed from Solar Two and Solar Tres with appropriate scale up and available industry data.
- Boeing is a key player in developing tower technology with present focus on Solar Tres
- The business group that addresses CSP technology has the resources of one of the largest, reputable companies in the United States.
- Boeing is presently spending significant money (not disclosed due to confidentiality) on industry research and development. They spent $2 million of funds for research on Solar Two.

E.7.2 Technology Improvement

E.7.2.1 Efficiency

Table E-41 — Receiver Efficiency

	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
	—	2004	2006	2008	2012	2018
Receiver Efficiency	76.0%	78.3%	80.9%	83.1%	83.5%	82.0%
Defocus, Dump, Startup, Clouds	90.0%	92.7%	93.4%	93.4%	93.4%	93.4%
Absorbance	93.0%	93.0%	93.0%	94.0%	94.5%	94.5%
Receiver Thermal Losses	90.7%	90.9%	93.1%	94.7%	94.7%	92.9%
Change in Receiver Efficiency	—	2.39%	2.53%	2.23%	0.44%	-1.59%
Percent Change in Field Area	—	0.4%	0.51%	0.96%	1.06%	0.81%

The increased efficiency is from the following:

- Reduction in heat loss, which is approximately proportional to reduction in receiver surface area per incident power
- Increase of receiver absorbtivity through Industry Research & Development (IR&D)
- Decrease of receiver emissivity from selected coatings achieved through IR&D
- High nickel tubes allow higher solar flux and smaller tube surface for Solar 200.
- Improved heliostat aiming allows higher average flux on receiver
- Gradual increase in solar flux as operating experience is gained from the preceding plant
- Improved insulation and receiver header oven covers further reduces heat loss.

The efficiency changes and basis for each change in plant size is shown in Section E.3.6.

E.7.2.2 Other

Solar Two demonstrated manufacturing, construction and operation of the molten salt tower receiver. The receiver system efficiency and thermal storage efficiency exceeded or met expectations. The feasibility of dispatchable solar power was proven. There were several problems encountered that have been evaluated and have been resolved for Solar Tres and future plants.

- Downcomer piping failed near a horizontal pipe section below the receiver. Both the receiver and the down-comer piping grow considerably as they heat up to the 1,050°F (565°C) operating temperature. The piping design did not adequately cover the downcomers thermal growth during heat-up and cool down cycles. Larger expansion loops and a material change eliminated this concern.
- Receiver fill operation was changed from a flood fill to a more rapid serpentine fill technique.
- A number of receiver tubes developed slow leaks due to intergranular corrosion (IGC). The new tube material eliminated this problem.
- However, this change did not solve all receiver startup problems. As reported in "An Evaluation of Molten-Salt Power Towers Including Results of the Solar Two Project":

> An inability to heat receiver header ovens to 450°F (232°C) often delayed introduction of salt into the receiver. In addition, frozen tubes (as revealed by the infrared camera) often delayed the transition from receiver fill to normal operation. During the downcomer outage, project personnel implemented a number of modifications, including changing the oven-to-tube seal, adding heat trace behind the tubes at the oven-to-tube interface, and adding baffles between oven covers. Since these modifications were only implemented on several of the west (windward) lower oven covers, they did not eliminate all receiver startup delays. The modifications did, however, indicate that receiver startup delays could be minimized or eliminated with some simple design changes. One simple change would be to locate the tube clips away from the oven-to-tube interface area, since the tube clips represent a heat sink, which is hard to heat when located at this interface. Another modification would be to change the oven-to-tube sealing technique.

Design improvements for Solar Tres include the following:

- Change from 316SS to high nickel alloy tubes, which allows higher peak solar flux and is "essentially immune" to chloride stress corrosion cracking (Boeing undated). The new material was tested at Sandia and in Solar Two in a full size panel.
- Redesign with inexpensive receiver cover ovens
- Improved inlet vessel operational design (Boeing patent pending)
- Simpler header design with fewer subcomponent parts (Boeing patent pending)
- Reduction of piping and valves.

E.7.3 Economy of Scale

Table E-42 — Economies of Scale (Boeing)

	Solar One	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
	1988	**1999**	**2004**	**2006**	**2008**	**2012**	**2018**
Net Plant Size – Thermal, MWt	46	42	120	380	700	1,400	1,400
Receiver Surface Area, m^2	—	100	269	710	1,120	1,960	1,960
Receiver System Capital Cost, $1,000/$m^2$	—	$91	$59	$37	$30	$23	$24
Receiver System Capital Cost –Boeing, $M	—	$9.1	$16.0	$26.0	$34.0	$46.0	$48.3
Receiver System Capital Cost with a Scaling Factor of 0.7 (calculated from Solar Two based on increase in surface area)	—	—	$18.2	$31.6	$35.8	$50.3	$50.8

Boeing, based on their experience in manufacturing receivers and similar components, used a scaling factor of 0.7. The estimated capital cost for receivers was calculated based on a scaling factor of 0.7, as shown in Table E-42. The difference between the capital cost calculated with a scale-up of 0.7 and the projected capital cost is a cost reduction, which is attributed to technical and volume production; for example, the receiver cost for Solar 50 is estimated to be $26 million. The cost projection based on a scaling factor of 0.7 would be $31.6 million [Receiver Cost for Solar 100 = $16 x $(710/269)^{0.7}$ = $31.6 million]. The difference is $5.6, which is attributed to technical improvements and production volume, as discussed in Section E.7.4.

E.7.4 Production Volume

Since only one receiver is manufactured for each plant, production volume is not a consideration for cost improvement when evaluating a single plant. However, fabrication learning curve from previous projects will provide cost improvements due to the repetitive assembly related with manufacturing receiver panels and their subcomponent parts. For example, in Solar Tres, 6,000 clips are welded onto 850 individual tubes that are then welded to 34 headers, which are part of 17 identical receiver panels. Boeing is expecting 85% to 90% learning curve based on previous experience. Boeing has also identified cost improvements due to improved manufacturing tooling and automation and quantity discount of material, which are reasonable assumptions. Material and components are about 35% of receiver costs.

Table E-43 — Effect of Production Volume (Percent of Total Savings)

	Solar One	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
	1988	**1999**	**2004**	**2006**	**2008**	**2012**	**2018**
Net Plant Size – Thermal, MWt	46	42	120	380	700	1,400	1,400
Fabrication Learning Curve, %	—	—	5%	9%	7%	3%	—
Improved Manufacturing Tools and Automation, %	—	—	2%	3%	3%	1%	—
Quantity discount of material, %	—	—	0%	2%	2%	1%	—
Total, %	—	—	7%	14%	12%	5%	—

E.7.5 Cost Comparison

Table E-44 — Total Installed Cost

Case	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 220
Year	**2004**	**2006**	**2008**	**2012**	**2018**
Receiver – Boeing, $M	$16.0	$26.0	$34.0	$46.0	$48.3
Receiver – SunLab, $M	$14.0	$19.8	$25.0	$36.9	$34.4

E.7.6 Cost Improvements

Cost Improvements are evaluated against three categories: technical (efficiency and design optimization), economy of scale and volume production. The cost reduction determined by S&L for the receiver is an average of 46% due to technical, 40% due to scale-up and 14% due to volume production. The method used by S&L is shown below, and the detailed calculation is shown in Section E.7.7.

Cost Savings = Cost Savings from Technical + Cost Savings from Scale-up + Cost savings from Volume Production

Where:

Cost savings from Technical = Cost savings due to receiver flux increase + Cost savings due to receiver improved efficiency + Cost savings in heliostat field size due to improvements in receiver efficiency.

Cost savings from Scale-up = Capital cost based on 0.7 scaling factor minus Capital cost based on 1.0 scaling factor

Cost savings from Volume Production = Cost savings from manufacturing receiver panels and subcomponent parts.

The cost improvements and basis for the improvements for each change in plant size are shown in Section 5.6.

E.7.7 Receiver Efficiency Improvements

Table E-45 — Sargent & Lundy Determination of Receiver Cost Reduction Breakout

		Solar One	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
	Abbr.	1988	1999	2004	2006	2008	2012	2018
Net Plant Size – Thermal, MWt		46	42	120	380	700	1,400	1,400
Receiver Surface Area, m^2		—	100	269	710	1,120	1,960	34.4
Receiver Peak Incident Flux, MW/m^2		0.45	0.8	0.95	1.2	1.4	1.6	1.6
Ratio Average/Peak Incident Flux		43%	60%	51%	50%	50%	50%	50%
Receiver Average Incident Flux, MW/m^2		0.20	0.48	0.49	0.6	0.7	0.8	0.8
Receiver Efficiency (annual)		64.8%	76%	78.2%	79.9%	82.3%	83.2%	81.3%
Receiver System Capital Cost –Boeing, \$M	TC	—	\$9.1	\$16.0	\$26.0	\$34.0	\$46.0	\$48.3
Receiver Capital Cost with a Scaling Factor of 0.7 (calculated from Solar Two based on increase in surface area), \$M	TC_S	—	—	\$18.2	\$31.6	\$35.8	\$50.3	\$50.8
Receiver Capital Cost without a scaling factor (e.g., scaling factor = 1), \$M	TC_{NS}	—	—	\$24.5	\$42.3	\$41.0	\$59.5	\$60.4
Cost Savings from scaling factor [$CS_s = TC_s - TC_{NS}$]	CS_S	—	—	\$6.3	\$10.7	\$5.2	\$9.2	\$9.6
Receiver Cost Savings from Smaller Receivers due to higher flux levels								
Area with Solar Two avg. flux, m^2		—	—	274	893	1,643	3,285	3,336
Cost with Solar Two avg. flux and scaling factor, \$M	TC_{S+F}	—	—	\$18.5	\$37.0	\$46.8	\$72.2	\$73.0
Cost savings from flux increase [$CS_F = TC_S - TC_{S+F}$], \$M	CS_F	—	—	0.26	5.48	11.00	21.91	22.15

		Solar One	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
	Abbr.	1988	1999	2004	2006	2008	2012	2018
Receiver cost savings from increased efficiency due to higher flux levels								
Area with Solar Two avg. flux, m^2		—	—	277	747	1,213	2,148	2,129
Cost with Solar Two avg. flux and scaling factor, $M	TC_{S+RE}	—	—	18.6	32.7	37.8	53.6	48.7
Cost savings from flux increase [CS_{RE} = TC_S -TC_{S+RE}], $M	CS_{RE}	—	—	0.38	1.14	2.06	3.33	-2.10
Heliostat cost savings (collector area) from increased receiver efficiency – from Table E-8), $M	CS_{HE}	—	—	$3.31	$2.21	$0.7	$0.042	$-0.958
Total Cost Savings from technology [CS_{RE} = CS_F +CS_{RE} + CS_{HE}]	CS_T	—	—	3.95	8.83	13.76	25.29	19.09
Cost Savings from Volume Production [CSv = TCs – TC – CS_F – CS_{RE}]	CS_V	—	—	1.56	5.56	1.77	4.30	2.54
Cost Reduction from Scaling, $M	CS_s	—	—	6.3	10.7	5.2	9.2	9.6
Cost Reduction from Technical, $M	CS_t	—	—	3.9	8.8	13.8	25.3	19.1
Cost Reduction from Production Vol., $M	CS_V	—	—	2.2	5.6	1.8	4.3	2.5
Total Cost Reduction, including receiver and heliostat field, $M	CS_T	—	—	12.4	25.1	20.8	38.8	31.2
Cost Reduction from Technical, %	CS_t	—	—	32%	35%	66%	65%	31%
Cost Reduction from Scaling, %	CS_s	—	—	50%	43%	25%	24%	61%
Cost Reduction from Production Vol., %	CS_V	—	—	18%	22%	9%	11%	8%

E.8 THERMAL STORAGE

E.8.1 Capital Cost

The capital cost estimate for the thermal storage system is shown in Table E-46.

Table E-46 — Capital Cost for Thermal Storage – SunLab Reference Case

	Solar One	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
	1988	**1999**	**2004**	**2006**	**2008**	**2012**	**2018**
Thermal Storage - Duration at peak output, hr	N/A	3	16	16	13	13	12.7
Net Plant Size – Thermal, MWt	46	42	120	380	700	1,400	1,400
Thermal Storage System Direct Cost, $M	$20.1	$3.7	$5.9	$18.7	$28.9	$56.3	$57.2
Thermal Storage System Direct Cost, $/kWe	—	—	$431	$374	$289	$281	$261

The SunLab cost estimate for the capital cost for thermal storage is reasonable based on the following:

- The cost estimate is a definitive cost estimate based on detailed design drawings and material takeoff.
- The unit cost parameters are within typical industry values.
- The contingency is 10%.
- The binary nitrate salt cost is based on vendor quotes, which includes shipping.

E.8.2 Technology Improvement

E.8.2.1 Efficiency

The storage design point efficiency is projected at 99.9% for all cases. The efficiency of Solar Two was demonstrated at 99.9%, and since there is no significant technology changes, it can be expected to remain constant. With larger plants, tank volume-to-surface-area ratio increases further, which increases storage efficiencies.

E.8.2.2 Discussion

Solar Two demonstrated molten salt as a viable, large-scale thermal energy storage medium. Energy storage efficiencies of 99% were achieved. The design, construction, and performance of large, field-erected, externally insulated tanks for storing molten salt were demonstrated.

There are several ongoing studies for improvement of the design and construction including the following:

- Alternative valve designs for hot salt service.
- Alternative salt downcomer designs.
- Materials testing on stainless steels 347 and 321 are planned to demonstrate their resistance to IGC in salt service.

E.8.3 Economy of Scale

Table E-47— Economy of Scale for Thermal Storage

Steam Generator	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Direct Cost (SunLab)	\$3.70	\$5.90	\$18.70	\$29.30	\$56.30	\$57.30
Cost Reduction Due to Scaling based on Scaling Factor of 0.78	—	—	\$3.75	\$5.81	\$9.69	\$9.40
Cost Reduction Due to Scaling, \$M	—	—	\$14.50	\$30.12	\$50.31	\$56.30
Cost Due to Technology Improvements, \$M	—	—	\$4.20	(\$0.82)	\$5.99	\$1.00
Cost Due to Technology Improvement, %	—	—	22.5%	-2.8%	10.6%	1.7%

The scale-up from Solar Two to Solar 220 thermal storage for the SunLab cost estimate is 0.78. This is reasonable based on the following:

- The main components are the hot storage tank, cold storage tank and piping.
- The scale-up was calculated based on the difference between the actual cost for Solar Two and vendor quotes for Solar100 (Central Receiver Utility Studies 1989)
- The SunLab estimate is within the range of expected scale-up factors based on S&L's experience with similar equipment in electric power plants.

E.8.4 Production Volume

Since the thermal storage system is comprised of single components, production volume is not a consideration for cost improvement.

E.8.5 Cost Improvements—Thermal Storage and Parasitic

Cost improvements for thermal storage and parasitic were evaluated against technical efficiency improvements. Parasitic was included since thermal storage is the key contributor to minimizing parasitic losses. The cost improvements are shown in Table E-48.

Table E-48 – Thermal Storage and Parasitic Cost Improvements Due to Technology (Efficiency) Improvements (Effect on Collector Field)

	Solar Two to Solar Tres	Solar Tres to Solar 50	Solar 50 to Solar 100	Solar 100 to Solar 200	Solar 200 to Solar 220
Thermal Storage					
Percent Effect on Cost Reduction, %	-0.4%	-0.1%	-0.0%	-0.0%	-0.0%
Cost Reduction, $M	-$0.41	-$0.17	-$0.02	-$0.01	-$0.05
Parasitic					
Percent Effect on Cost Reduction, %	-3.6%	-0.7%	-0.1%	-0.1%	-0.2%
Cost Reduction, $M	-$3.72	-$1.39	-$0.36	-$0.25	-$1.08

E.8.6 Cost Improvements

Cost Improvements were evaluated by S&L against three categories: technical (efficiency and design optimization), economy of scale, and volume production. The cost reductions determined by S&L for the thermal storage system is an average of 7% due to technical improvements, 93% for scale-up, and 0% for volume production.

E.9 STEAM GENERATOR

E.9.1 Capital Cost

The capital cost estimated by SunLab for the steam generator system is shown in Table E-49.

Table E-49 — Steam Generator Capital Cost

	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Direct Cost	—	$1.6	$3.7	$5.8	$9.4	$9.3

The SunLab cost estimate for the steam generator (superheater, evaporator, preheater, and reheater) is based on actual costs for Solar Two and vendor quotes for a 100-MWe plant (ref: ASND93-7084).

E.9.2 Technology Improvement

The Solar Two design of the steam generator consisted of a straight-shell, U -tube preheater (salt on the shell side); a kettle-boiler evaporator (salt in the U-tubes); and a straight-shell, U -tube superheater (salt on the shell side). Intergranular corrosion (IGC) was a problem in some areas where high- carbon stainless steel piping and fittings were used for containment of molten salt. Future molten-salt power tower designs will use the following:

- Piping materials that are not susceptible to IGC.
- Four tube-in-shell vessels (preheater, evaporator, superheater, reheater) with salt on the shell side.
- Evaporator will be of a forced circulation design with separate steam drum.
- Vessels stacked to provide simplified drain and maintenance procedures.

The Solar Two demonstration project identified the following problems with the steam generator system:

- A number of receiver tubes developed slow leaks due to intergranular corrosion (IGC). The new tube material eliminated this problem.
- Poor water mixing in the evaporator shell which lead to salt freeze thaw cycles on the tubes resulting in a tube rupture and strained tubes.
- The recirculation pump's seals added considerable amount of cold water, which decreased the temperature of the recirculation flow.
- The preheater was bypassed during startup to prevent salt from freezing, but it resulted in feedwater entering the evaporator below minimum design temperature.

All problems were solved by the following means:

- Repairing the evaporator tubes and modifications of evaporator spargers,
- Adding a startup feedwater heater, adding a higher capacity canned-rotor recirculation pump,
- Eliminating the preheater bypass line,
- Adding a feedwater valve to the evaporator inlet piping, and
- Modifying the startup procedure to reflect the new configuration and incorporate lessons learned from the tube rupture.

The modifications solved the problems as mentioned in the report: "No further tube ruptures occurred; temperature stratification in the evaporator was essentially eliminated; and the system performed more reliably for the remainder of the project. Operating experience also revealed that varying pump speed could reliably control salt flow to the SGS. This experience eliminated the need for flow control valves on the SGS salt supply piping."

The technology and lessons learned have been applied to the next generation design of Solar Tres. The successful operation of the system after repairs and modifications indicate that there is a low risk of significant problems occurring with the scale-up of the system.

E.9.3 Economy of Scale

Table E-50 — Economy of Scale for Steam Generator

Steam Generator	Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Direct Cost	—	$1.6	$3.7	$5.8	$9.4	$9.3
Cost Reduction Attributed to Scaling based on Scaling Factor of 0.74	—	—	$3.75	$5.81	$9.69	$9.69

Note: The difference between cost reduction due to scaling and direct cost is attributed to technology improvements and calculates to an average of 3.7%.

The cost estimates for the other size plants were calculated based on a scaling factor of 0.7, which was calculated from the steam generator size and cost of Solar Two to the quotes for Solar 100. The cost estimate is reasonable based on the following:

- The cost for Solar Two is an actual cost.
- The cost estimate for Solar 100 is based on vendor's designs and quotes.
- The SunLab estimate is within the range of expected scale-up factors based on S&L's experience with similar equipment in electric power plants.
- A comparison of Solar Two of the preheater, evaporator, and superheater area to Solar 100 preheater, evaporator, and superheater results in a scaling factor of 0.69. Solar 100 has a reheater and the SunLab calculation included the reheater.
- The steam generator design is based on known and proven heat exchanger technology.
- A contingency of 10% is included in the cost estimate, which is reasonable.

The SunLab cost estimate for the pumps is based on Solar Two actual costs and Solar Tres detailed budgetary quotes from vendors. Motor costs are based on standard industry motor costs. The cost estimate is reasonable based on the following:

- The cost for Solar Two is an actual cost
- The cost estimate for Solar Tres in based on actual budgetary quotes
- Motors are not a unique design but standard industry available models
- The cost scaling factors calculated between Solar Two and Solar Tres are lower than industry standard based on MWt: 0.65 for cold pumps and 0.55 for hot pumps. The reason is based on material changes for hot components, which are more costly.

E.9.4 Production Volume

Since the steam generator system is comprised of single components, production volume is not a consideration for cost improvement.

E.9.5 Cost Improvements

Cost Improvements were evaluated by S&L against three categories: technical (efficiency and design optimization), economy of scale, and volume production. The cost reductions determined by S&L for the steam generator system is an average of 4% due to technical improvements, 96% for scale-up, and 0% for volume production.

E.10 BALANCE OF PLANT

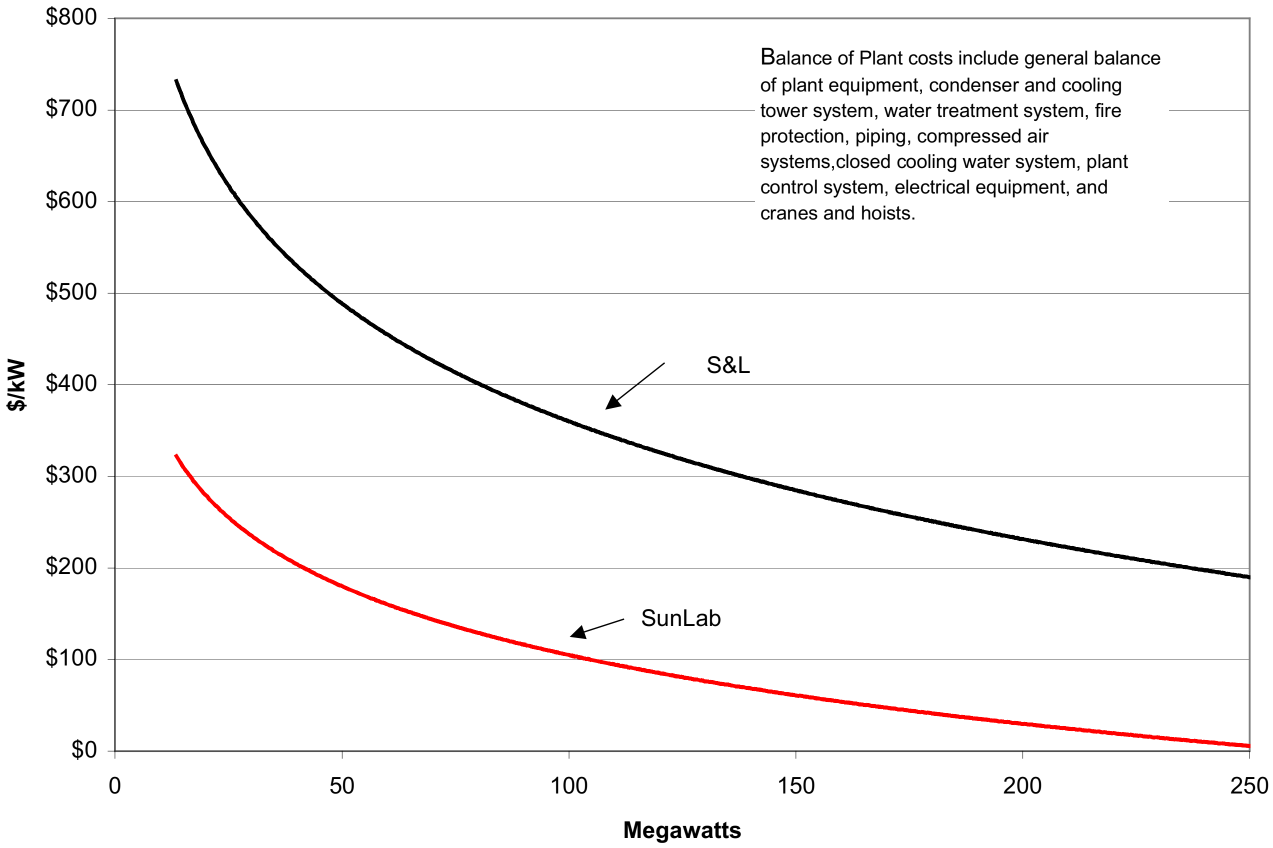
E.10.1 Capital Cost

Sargent & Lundy estimated the cost for the balance of plant based on the SOAPP model, compared it to our internal database, and then adjusted the output for labor and productivity rates in the Southwest. The results of our review are shown in Table E-51 and Figure E-12. The balance-of-plant costs include general balance-of-plant equipment, condenser and cooling tower system, water treatment system, fire protection, piping, compressed air systems, closed cooling water system, instrumentation, electrical equipment, and cranes and hoists.

Table E-51 — Capital Cost of Balance of Plant

		Solar Two	Solar Tres	Solar 50	Solar 100	Solar 200	Solar 220
Power Block	MWe	—	13.5	50	100	200	220
SunLab	$M	—	$4.8	$6.5	$7.8	$9.6	$9.9
	$/kWe	—	$356	$130	$78	$48	$45
S&L	$M	—	$10	$24.5	$36.7	$33.8	$35.5
	$/kWe	—	$741	$490	$367	$169	$148

Figure E-12 — Balance of Plant



Balance of Plant costs include general balance of plant equipment, condenser and cooling tower system, water treatment system, fire protection, piping, compressed air systems,closed cooling water system, plant control system, electrical equipment, and cranes and hoists.

E.10.2 Technology Improvements

There are no efficiency improvements projected for balance of plant.

E.10.3 Economy of Scale

There are recognized scale-up cost reductions for the balance of plant. Using the SOAPP software program (SOAPP undated) and S&L's internal database, the scale-up factor was estimated for the increasing the balance of plant from 13.5 MW to 200 MW, as depicted on Figure E-12. The S&L trend curve is expressed as follows:

$$Y = (461.3)\ x^{-0.1896}$$

Where:

Y = \$/kW
x = MWe

E.10.4 Production Volume

Production volume is not a consideration for cost reduction.

E.10.5 Cost Improvements

Cost Improvements were evaluated by S&L against three categories: technical (efficiency and design optimization), economy of scale, and volume production. The cost reductions determined by S&L for the balance of plant is an average of 0% due to technical improvements, 100% for scale-up, and 0% for volume production.

E.11 CAPITAL COST COMPARISON

The SunLab model projects tower plant capital and O&M costs based on various technology advances and commercial deployment predictions. The SunLab projections are considered the best-case analysis where the technology is optimized and a high deployment rate is achieved. S&L developed capital and O&M costs 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, SunLab's and S&L's, provides a band in which the costs can be expected to be, assuming the parabolic trough technology reaches the projected levels of deployment. A comparison of key parameters used for the estimates is summarized on Table E-52.

Table E-52 — Key Parameters Comparison

	2004		2007		2010		2015		2020	
	SunLab	S&L	SunLab	S&L	SunLab	S&L	SunLab	S&L	SunLab	S&L
Deployment, MW	13.5	13.5	50	50	100	100	200	200	220	200
Cumulative Deployment, MW	13.5	13.5	164	64	914	264	3,914	814	8,734	2,614
Net Annual Solar Efficiency	13.7%	13.0%	16.1%	15.5%	16.6%	16.1%	16.9%	16.5%	18.1%	16.5%
Heliostat, $/m^2	$145	$160	$127	$150	$107	$134	$96	$124	$75	$117

The significant differences between the SunLab Reference Case and the S&L estimate are the following:

- **Deployment.** SunLab projected 8.7 GWe whereas S&L projected 2.6 GWe.
- **Net Annual Solar Efficiencies.** S&L projected the net annual solar efficiency to be lower based on proven results and conservative design enhancements. S&L did not include the advanced eliostat design and advance higher temperature steam turbine in their base case estimate.
- **Heliostat Cost.** S&L cost estimate is based on a detailed evaluation of existing cost estimates and independent projection.
- **Electric Power.** S&L cost estimate is based on the latest industry information and is lower than the SunLab estimate.
- **Balance of Plant.** S&L cost estimate is based on the latest industry information and is higher than the SunLab estimate.
- **O&M Costs.** S&L estimate is based evaluation of the SunLab projection, visit to the SEGS site, and our review of conventional power plants. The main difference is scaled-up costs due to the increase in field size for grounds and vehicle maintenance, average burden rate and raw water cost.
- **Engineering, Management and Development.** SunLab projected that the Engineering, Management and Development at 7.8% of cost. S&L projected the cost to be 15%, based on recent industry experience in developing independent power plants.
- **Contingency.** SunLab projected the contingency at 7.7%. S&L projected the contingency to be 11.8% for the cost estimate and 15% for cost reductions.

E.12 LEVELIZED ENERGY COST

The projections by SunLab and S&L for capital cost and operations & maintenance were used to estimate levelized energy costs (LEC). After completing the report, SunLab revised its reference case (from August 2002 to October 2002) as shown below. The Sunlab LEC projections are based on the October 2002 reference case.

Revised SunLab Reference Case

	Solar Two 1999	Solar 15 2004	Solar 50 2006	Solar 100 2008	Solar 200 2014	Solar 220 2018
Net Electrical (MWe)	10	13.7	50	100	200	220
Plant Size Solar (MWt)	42	120	380	700	1400	1400
Heliostat Size (m^2)	39/95	95	95	148	148	148
Heliostat Field (m^2)	81,400	231,000	715,000	1,317,000	2,614,000	2,651,000
Annual Solar-to-Electicity Efficiency	7.6%	13.7%	15.7%	16.5%	16.8%	17.8%
Capital Cost ($/kWe)	—	7,180	4,160	3,160	2,700	2,340
O&M Annual Cost ($k)	—	2,489	3,166	4,005	5,893	6,006
LEC ($/kWh)	—	$114.8	$61.5	$47.6	$39.6	$35.0

The cost estimates were inputted to the financial model developed by S&L (see Appendix B for a description of the financial model). The results are shown in Table E-53.

Table E-53 — Capital Cost, O&M Costs and Levelized Energy Cost Summary: SunLab and S&L

	Near Term		Mid Term		Long Term	
	SunLab	S&L	SunLab	S&L	SunLab	S&L
	Solar Tres USA		Solar 100		Solar 220	Solar 200
	2004	2004	2008	2010	2018	2020
Capital Cost, $/MWh	$77.4	$97.1	$36.3	$52.9	$27.0	$41.8
Fixed O&M Costs, $/MWh	$37.4	$46.1	$11.3	$15.3	$8.0	$12.9
Variable O&M Costs, $/MWh	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
LEC, $/MWh	$114.8	$143.1	$47.6	$68.2	$35.0	$54.7

SunLab – Deployment of 8.7 GWe / S&L – Deployment of 2.6 GWe

Sargent & Lundy’s estimate of the direct capital cost and operation & maintenance costs for the near-term deployment includes a contingency of about 10%. Based on our review of the SunLab cost estimate, which we determined was based on industry cost data and engineering judgment, the cost estimate for the near-term deployment (Solar Tres) is reasonable. The projection from near-term deployment (2003) to long-term deployment (2020) includes cost reduction due to technology improvements, scaling, and volume production. S&L included a composite contingency of 15% for cost reductions (15% for technology, 10% for scaling, and 20% for volume production). For comparison, the effect of deployment and annual net efficiencies are shown in Table E-54.

Table E-54 — Impact of Deployment and Net Solar-to-Electric Efficiency on LEC

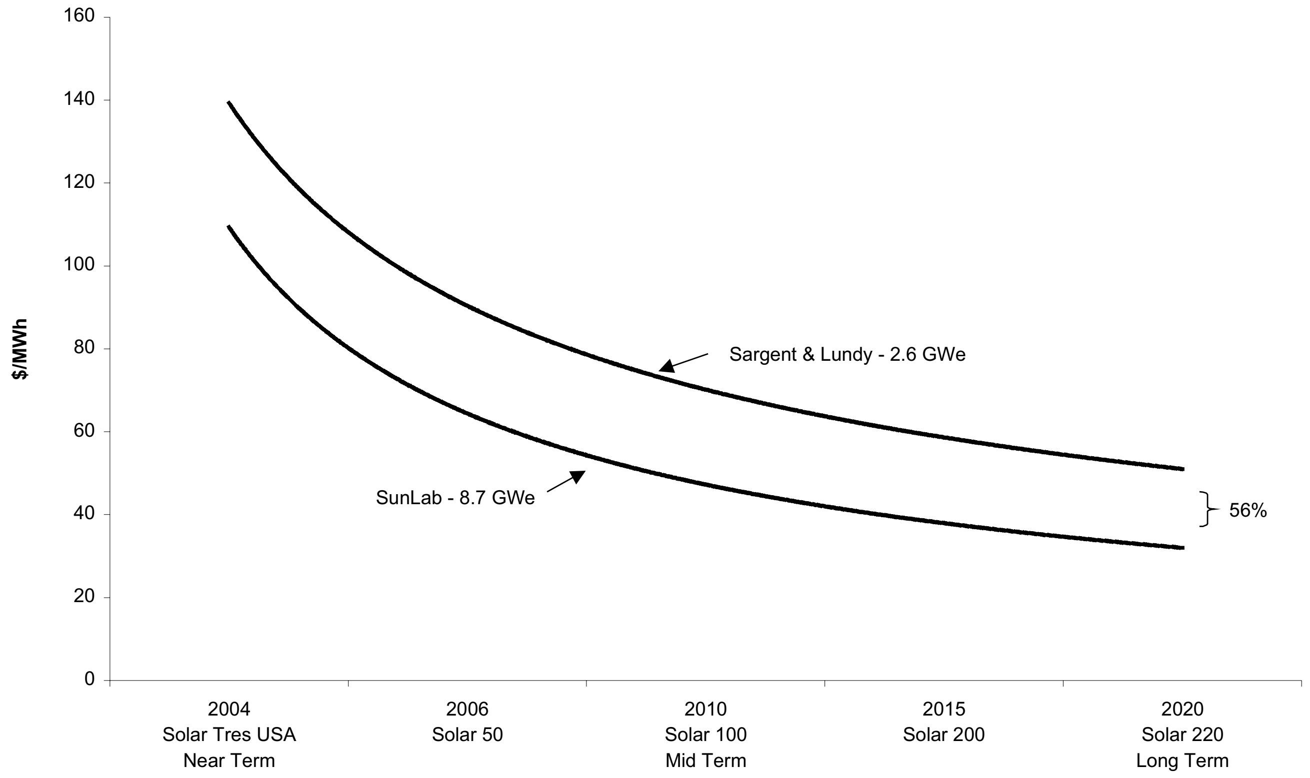
Year 2020	Total Deployment (GWe)	Net Solar-to-Electric Efficiency (%)	LEC	
			($/kWh)	Percent change from S&L Base Case
SunLab	8.7	18.1	0.0350	SunLab Base
S&L	8.7	16.5*	0.0524	-4.2%
S&L	4.7	16.5*	0.0538	-1.6%
S&L	2.6	16.5*	0.0547	S&L Base
S&L	1.2	16.5*	0.0559	2.2%
S&L	2.6**	17.3	0.0476	-13.0%
S&L	2.6**	16.5	0.0547	S&L Base
S&L	2.6**	14.6	0.0590	7.9%

* Fixed net solar-to-electric efficiency

** Fixed total deployment.

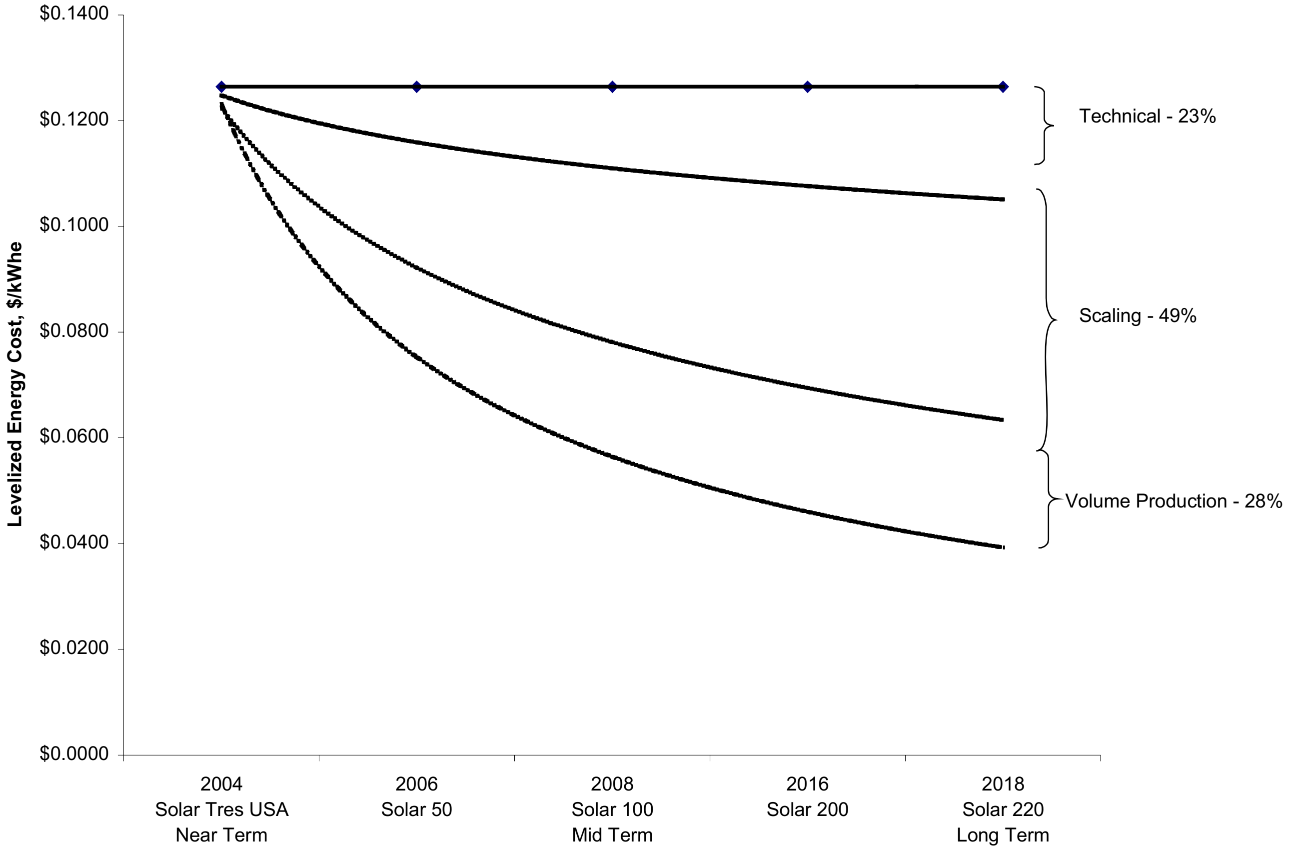
The range of LEC between the SunLab cost estimate and S&L's estimate is about 56% as shown in Figure E-13.

Figure E-13 — Levelized Energy Cost Comparison: SunLab and S&L



Cost improvements were evaluated by S&L against three categories: technical improvements, scale-up, and production volume. The contribution of these three categories against the S&L LEC projection is shown in Figure E-14.

Figure E-14 — Sargent & Lundy LEC Projection Breakout by Category



The major contributor to cost reduction from Solar Tres to Solar 50 is due to the increase in electrical generation (13.5 MWe to 50 MWe) as shown in Figure E-15. The annual net energy production increased from 93.2 GWh/yr to 331 GWh/yr.

Figure E-15 — Comparison of SunLab and S&L LEC Estimates: 2004 to 2020