03-SC-002 Project Engineering Design (PED)
Linac Coherent Light Source
Stanford Linear Accelerator Center

(Changes from the FY2005 Congressional Budget Request are denoted with a vertical line in the left margin.)

1. Construction Schedule History

	Fiscal Quarter				Total Estimated Cost[1] ($000)
	A-E Work Initiated	A-E Work Completed	Physical Construction Start	Physical Project Complete	
FY2003 Budget Request *(Preliminary Estimate)*	1Q 2003	2Q 2005	N/A	N/A	33,500
FY2004 Budget Request	1Q 2003	4Q 2006	N/A	N/A	36,000
FY2005 Budget Request	2Q 2003	4Q 2006	N/A	N/A	36,000

2. Financial Schedule

(dollars in thousands)

Fiscal Year	Appropriations	Obligations	Costs
2003	5,925 [2]	5,925	3,644
2004	7,456 [2]	7,456	9,000
2005	20,075 [2]	20,075	17,756
2006	2,544 [2]	2,544	5,600

3. Project Description, Justification and Scope

These funds allow the Linac Coherent Light Source (LCLS), located at the Stanford Linear Accelerator Center (SLAC), to proceed from conceptual design into preliminary design (Title I) and definitive design (Title II). The design effort will be sufficient to assure project feasibility, define the scope, provide detailed estimates of construction costs based on the approved design, working drawings and specifications, and provide construction schedules including procurements. The design effort will ensure that construction can physically start or long-lead procurements and activities can be initiated that preserve the LCLS schedule.

The purpose of the LCLS Project is to provide laser-like radiation in the x-ray region of the spectrum that is 10 billion times greater in peak brightness than any existing coherent x-ray light source. This advance in brightness is similar to that of a synchrotron over a 1960's laboratory x-ray tube. Synchrotrons revolutionized

[1] The preliminary estimate of the TEC and TPC are $273,000,000 and $315,000,000, respectively. The baseline TEC and TPC will be established at Critical Decision 2 (Approve Performance Baseline).

[2] PED funding was reduced as a result of the FY2003 general reduction and rescission by $74,765 and as a result of the FY2004 rescission by $44,250. This total reduction is restored in FY2005 and FY2006 to maintain the TEC and project scope.

science across disciplines ranging from atomic physics to structural biology. Advances from the LCLS are expected to be equally dramatic. The LCLS Project will provide the first demonstration of an x-ray free-electron-laser (FEL) in the 1.5–15 Å range and will apply these extraordinary, high-brightness x-rays to an initial set of scientific problems. This will be the world's first such facility.

The LCLS is based on the existing SLAC linac. The SLAC linac can accelerate electrons or positrons to 50 GeV for colliding beam experiments and for nuclear and high-energy physics experiments on fixed targets. At present, the first two-thirds of the linac is being used to inject electrons and positrons into PEP-II, and the entire linac is used for fixed target experiments. When the LCLS is completed, the latter activity will be limited to 25% of the available beam time and the last one-third of the linac will be available for the LCLS a minimum of 75% of the available beam time. For the LCLS, the linac will produce high-brightness 5 - 15 GeV electron bunches at a 120 Hz repetition rate. When traveling through the new 120-meter long LCLS undulator, these electron bunches will amplify the emitted x-ray radiation to produce an intense, coherent x-ray beam for scientific research.

The LCLS makes use of technologies developed for the SLAC and the next generation of linear colliders, as well as the progress in the production of intense electron beams with radiofrequency photocathode guns. These advances in the creation, compression, transport, and monitoring of bright electron beams make it possible to base this next generation of x-ray synchrotron radiation sources on linear accelerators rather than on storage rings.

The LCLS will have properties vastly exceeding those of current x-ray sources (both synchrotron radiation light sources and so-called "table-top" x-ray lasers) in three key areas: peak brightness, coherence (*i.e.,* laser-like properties), and ultrashort pulses. The peak brightness of the LCLS is 10 billion times greater than current synchrotrons, providing over 10^{11} x-ray photons in a pulse with duration of 230 femtoseconds. These characteristics of the LCLS will open new realms of scientific applications in the chemical, material, and biological sciences. The LCLS Scientific Advisory Committee, working in coordination with the broad scientific community, identified high priority initial experiments that are summarized in the document, *LCLS: The First Experiments*. These first five areas of experimentation are: fundamental studies of the interaction of intense x-ray pulses with simple atomic systems; use of the LCLS to create warm dense matter and plasmas; structural studies on single nanoscale particles and biomolecules; ultrafast dynamics in chemistry and solid-state physics; and studies of nanoscale structure and dynamics in condensed matter.

The experiments fall into two classes. The first follows the traditional role of x-rays to probe matter without modifying it, while the second utilizes the phenomenal intensity of the LCLS to excite matter in fundamentally new ways and to create new states in extreme conditions. The fundamental studies of the interactions of intense x-rays with simple atomic systems are necessary to lay the foundation for all interactions of the LCLS pulse with atoms embedded in molecules and condensed matter. The structural studies of individual particles or molecules make use of recent advances in imaging techniques for reconstructing molecular structures from diffraction patterns of non-crystalline samples. The enormous photon flux of the LCLS may make it feasible to determine the structure of a *single* biomolecule or small nanocrystal using only the diffraction pattern from a single moiety. This application has enormous potential in structural biology, particularly for important systems such as membrane proteins, which are virtually uncharacterized by x-ray crystallography because they are nearly impossible to crystallize. The last two sets of experiments make use of the extremely short pulse of the LCLS to follow dynamical processes in chemistry and condensed matter physics in real time. The use of ultrafast x-rays will open up entire new regimes of spatial and temporal resolution to both techniques.

The proposed LCLS Project requires a 135 MeV injector to be built at Sector 20 of the 30-sector SLAC linac to create the electron beam required for the x-ray FEL. The last one-third of the linac will be modified by adding two magnetic bunch compressors. Most of the linac and its infrastructure will remain unchanged. The existing components in the Final Focus Test Beam tunnel will be removed and replaced by a new undulator and associated equipment. Two new experimental buildings, the Near Hall and the Far Hall will be constructed and connected by a beam line tunnel. A Central Laboratory and Office Building will be constructed to provide laboratory and office space for LCLS users and serve as a center of excellence for basic research in x-ray physics and ultrafast science.

4. Details of Cost Estimate[3]

(dollars in thousands)

	Current Estimate	Previous Estimate
Design Phase		
Preliminary and Final Design costs (Design Drawings and Specifications)	25,900	26,000
Design Management costs (13.9% of TEC)	5,000	5,000
Project Management costs (14.2% of TEC)	5,100	5,000
Total Design Costs (100% of TEC)	36,000	36,000
Total, Line Item Costs (TEC)	36,000	36,000

5. Method of Performance

A Conceptual Design Report (CDR) for the project has been completed and reviewed. Key design activities are being specified in the areas of the injector, undulator, x-ray optics and experimental halls to reduce the risk of the project and accelerate the startup. Also, the LCLS management systems are being put in place and tested during the Project Engineering Design (PED) phase. These activities are managed by the LCLS Project Office at SLAC, with additional portions of the project being executed by staff at Argonne National Laboratory (ANL) and Lawrence Livermore National Laboratory (LLNL).

The design of technical systems is being accomplished by the three collaborating laboratories. The conventional construction design aspect (experimental halls, tunnel connecting the halls, and a Central Laboratory and Office Building) has been contracted to an experienced Architect/Engineering (A/E) firm to perform Title I and II design in FY2004.

6. Schedule of Project Funding

(dollars in thousands)

	Prior Year Costs	FY2004	FY2005	FY2006	Total
Facility Cost					
PED	3,644	9,000	17,756	5,600	36,000
Other project costs					
Conceptual design cost	1,470	0	0	0	1,470
Research and development costs	0	2,000	4,000	0	6,000
NEPA documentation costs	30	0	0	0	30
Total, Other Project Costs	1,500	2,000	4,000	0	7,500
Total Project Cost (TPC)	5,144	11,000	21,756	5,600	43,500

[3] This cost estimate includes design phase activities only. Construction funding is requested as an individual item under Project No. 05-R-320.

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05-R-320, Linac Coherent Light Source
Stanford Linear Accelerator Center

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A Performance Baseline has been established for long-lead procurements in order to request funds to ensure that selected critical path items can be set in motion in FY2005. The overall cost and schedule for the LCLS Project are only preliminary estimates. Plans call for a cost and schedule Performance Baseline to be developed during FY2004 and approved by the Acquisition Executive at the completion of preliminary design (Critical Decision 2–Approve Performance Baseline). Outyear funding projections (FY2007–FY2008) will support the completion of the LCLS at the Stanford Linear Accelerator Center and will be adjusted as necessary at Critical Decision 2 to support the Performance Baseline.

1. Construction Schedule History

	Fiscal Quarter				Total Estimated Cost [1] ($000)	Total Project Cost [1] ($000)
	A-E Work Initiated	A-E Work Completed	Physical Construction Start	Physical Construction Complete		
FY2006 Budget Request *(Current Estimate)*	2Q 2003	4Q 2006	1Q 2006	4Q 2008	273,000	315,000

2. Financial Schedule

(dollars in thousands)

Fiscal Year	Appropriations	Obligations	Costs
Project Engineering Design			
2003	5,925 [2]	5,925 [2]	3,644
2004	7,456 [2]	7,456 [2]	9,000
2005	20,075 [2]	20,075	17,756
2006	2,544 [2]	2,544	5,600
Construction			
2005	30,000 [3]	30,000	25,280
2006	83,000	83,000	78,625
2007	90,000	90,000	88,470
2008	34,000	34,000	44,625

[1] The preliminary estimate of the TEC and TPC are $273,000,000 and $315,000,000, respectively. The baseline TEC and TPC will be established at Critical Decision 2 (Approve Performance Baseline).

[2] PED funding was reduced by $74,765 as a result of the FY2003 general reduction and rescission and by $44,250 as a result of the FY2004 rescission. This total reduction is restored in FY2005 and FY2006 to maintain the TEC and project scope.

[3] FY2005 funding is for long-lead procurements. Project construction begins in FY 2006.

3. Project Description, Justification and Scope

These funds allow the Linac Coherent Light Source (LCLS), located at the Stanford Linear Accelerator Center (SLAC), to proceed from conceptual design into preliminary design (Title I), final design (Title II), and construction. The design effort will be sufficient to assure project feasibility, define the scope, provide detailed estimates of construction costs based on the approved design, working drawings and specifications, and provide construction schedules including procurements.

The purpose of the LCLS Project is to provide laser-like radiation in the x-ray region of the spectrum that is 10 billion times greater in peak brightness than any existing coherent x-ray light source. This advance in brightness is similar to that of a synchrotron over a 1960's laboratory x-ray tube. Synchrotrons revolutionized science across disciplines ranging from atomic physics to structural biology. Advances from the LCLS are expected to be equally dramatic. The LCLS Project will provide the first demonstration of an x-ray free-electron laser (FEL) in the 1.5 - 15 Å range and will apply these extraordinary, high-brightness x-rays to an initial set of scientific problems described below. This will be the world's first such facility.

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The LCLS makes use of technologies developed for SLAC and the next generation of linear colliders, as well as the progress in the production of intense electron beams with radiofrequency photocathode guns. These advances in the creation, compression, transport, and monitoring of bright electron beams make it possible to base this next generation of x-ray synchrotron radiation sources on linear accelerators rather than on storage rings.

The LCLS will have properties vastly exceeding those of current x-ray sources (both synchrotron radiation light sources and so-called "table-top" x-ray lasers) in three key areas: peak brightness, coherence (*i.e.*, laser like properties), and ultrashort pulses. The peak brightness of the LCLS is 10 billion times greater than current synchrotrons, providing 10^{11} x-ray photons in a pulse with duration of 230 femtoseconds or less. These characteristics of the LCLS will open new realms of scientific application in the chemical, material, and biological sciences.

The proposed LCLS Project requires a 135 MeV injector to be built at Sector 20 of the 30-sector SLAC linac to create the electron beam required for the x-ray FEL. The last one-third of the linac will be modified by adding two magnetic bunch compressors. Most of the linac and its infrastructure will remain unchanged. The existing components in the Final Focus Test Beam tunnel will be removed and replaced by a new undulator and associated equipment. Two new experimental buildings, the Near Hall and the Far Hall, will be constructed and connected by the beam line tunnel. A Central Laboratory Office Building will be added to the Near Hall to provide laboratory and office space for LCLS users and serve as a center of excellence for basic research in x-ray physics and ultrafast science.

The combined characteristics (spectral content, peak power, pulse duration, and coherence) of the LCLS beam are far beyond those of existing light sources. The demands placed on the x-ray instrumentation and optics required for the LCLS scientific experiments are unprecedented. The LCLS experimental program will commence with: measurements of the x-ray beam characteristics and tests of the capabilities of x-ray optics; instrumentation; and techniques required for full exploitation of the scientific potential of the facility. For this reason, the project scope includes a comprehensive suite of instrumentation for characterization of the x-ray beam and for early experiments in atomic, molecular, and optical physics. The experiments include x-ray multiphoton processes with isolated atoms, simple molecules, and clusters. Also included in the scope of the LCLS Project are the instrumentation and infrastructure necessary to support research at the LCLS, such as experiment hutches and associated interlock systems; computers for data collection and data analysis; devices for attenuation and collimation of the x-ray beam; prototype optics for manipulation of the intense x-ray beam; and synchronized pump lasers.

Beyond the scope of the LCLS construction project, an instrument development program will be executed to qualify and provide instruments for the LCLS. Instrument proposals will undergo a scientific peer review process to evaluate technical merit; those concepts that are accepted may then establish interface agreements with the LCLS Project. Expected funding sources include appropriated funds through the Department of Energy and other Federal agencies, private industry, and foreign entities. These instruments will all be delivered after completion of the LCLS line item project. The LCLS Scientific Advisory Committee, working in coordination with the broad scientific community, has already identified a number of high priority initial experiments that are summarized in the document, *LCLS: The First Experiments*. Five specific areas of experimentation are: fundamental studies of the interaction of intense x-ray pulses with simple atomic systems; use of LCLS to create warm dense matter and plasmas; structural studies on single nanoscale particles and biomolecules; ultrafast dynamics in chemistry and solid-state physics; and studies of nanoscale structure and dynamics in condensed matter. The combination of extreme brightness and short pulse length will make it possible to follow dynamical processes in chemistry and condensed matter physics in real time. It may also enable the determination of the structure of single biomolecules or small nanocrystals using only the diffraction pattern from a single moiety. This application has great potential in structural biology, particularly for important systems, such as membrane proteins, which are virtually uncharacterized by x-ray crystallography because they are nearly impossible to crystallize. Teams will form to propose instruments to address these and other scientific areas of inquiry.

FY2005 funding is for selected long-lead items, and the necessary modifications of existing facilities for the testing of those long-lead equipment. Early acquisition of selected critical path items will support pivotal schedule and technical aspects of the project. These include acquisition of the 135 MeV injector linac, acquisition of the undulator modules and the measurement system needed for verification of undulator performance, and acquisition of main linac magnets and radiofrequency systems required to produce electron beams meeting the stringent requirements of the LCLS FEL. Early acquisition of the 135 MeV injector is required in order that first tests of the FEL can begin. Acquisition of the undulators in FY2005 will allow delivery in FY2007, which in turn will enable achievement of performance goals in FY2008. The main linac magnets and radiofrequency systems must be ready for operation shortly after the injector has reached its performance goals.

4. Details of Cost Estimate [4]

(dollars in thousands)	Current Estimate	FY2005 Estimate
Design Phase		
Preliminary and Final Design Costs (Design Drawings and Specifications)	18,200	18,500
Design Management costs	5,000	5,000
Project Management costs (1.9% of TEC)	5,100	5,000
Total Design Costs	28,300	28,500
Construction Phase		
Improvements to Land	8,000	8,000
Buildings	42,100	36,300
Other Structures	1,800	1,800
Special Equipment	105,400	98,000
Inspection, Design and Project Liaison, Testing, Checkout and Acceptance	6,000	4,500
Construction Management (2.2% of TEC)	6,000	6,000
Project Management	13,700	11,700
Total Construction Costs	183,000	166,300
Contingencies		
Design Phase(2.8% of TEC)	7,700	7,500
Long-lead Procurements(2.2% of TEC)	6,000	6,000
Construction Phase(17.6% of TEC)	48,000	51,700
Total Contingencies	61,700	65,200
Total Line Item Costs (TEC)	273,000	260,000

5. Method of Performance

A Conceptual Design Report (CDR) for the project has been completed and reviewed. Key design activities are being specified in the areas of the injector, undulator, x-ray optics and experimental halls to reduce the risk of the project and accelerate the startup. Also, the LCLS management systems are being put in place and tested during the Project Engineering Design (PED) phase. These activities are managed by the LCLS Project Office at SLAC, with additional portions of the project being executed by staff at Argonne National Laboratory (ANL) and Lawrence Livermore National Laboratory (LLNL). The design of technical systems is being accomplished by the three collaborating laboratories.

The conventional construction design aspect (experimental halls, tunnel connecting the halls, and a Central Laboratory and Office Building) was contracted to an experienced architect/engineering (A/E) firm to perform Title I and II design in FY2004.

[4] Long-lead procurements are scheduled for FY 2005. The outyear (FY 2006-FY 2008) construction costs are estimates only. A baseline for outyear construction costs will be established when Critical Decision 2 for the LCLS Project is approved.

6. Schedule of Project Funding

(dollars in thousands)

	Prior Year Costs	FY2005	FY2006	Outyears	Totals
Facility Cost					
PED	12,644	17,756	5,600	0	36,000
Long-Lead Procurements	0	25,280	4,720	0	30,000
Construction	0	0	73,905	133,095	207,000
Total Line Item TEC	12,644	43,036	84,225	133,095	273,000
Other Project Costs					
Research & Development	1,750	4,250	0	0	6,000
Conceptual Design	1,470	0	0	0	1,470
NEPA Documentation Costs	30	0	0	0	30
Pre-operations	0	0	3,500	23,000	26,500
Spares	0	0	0	8,000	8,000
Total Other Project Costs	3,250	3,750	3,563	31,437	42,000
Total Project Cost (TPC)	15,894	46,786	87,788	164,532	315,000

7. Related Annual Funding Requirements

(FY2009 dollars in thousands)

	Current Estimate	Previous Estimate
Annual Facility Operating Costs	$50,000	N/A
Total Related Annual Funding	$50,000	N/A

FY2009 is expected to be the first full year of LCLS facility operations. The current estimate is preliminary and based on historical experience with operating similar types and sizes of facilities. This estimate will be refined as the LCLS Project matures.

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