Project X Research Design & Development Plan

V2.2
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I Introduction

Project X is a high intensity proton facility conceived to support a world-leading program in neutrino and flavor physics over the next two decades at Fermilab. The detailed configuration is available in the Project X Initial Configuration Document (ICD, available at http://projectx-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=83&extension=pdf). In this document, we describe a Research, Design, and Development (RD&D) plan to advance the project from the initial configuration to a technical design report.

Project X is comprised of an 8 GeV superconducting H^- linac, paired with the existing (but modified) Recycler and Main Injector to provide in excess of 2 MW of beam power throughout the energy range 60 – 120 GeV, simultaneous with greater than 650 kW of beam power at 8 GeV. A schematic view is shown in Figure I-1.

The linac operates at 5 Hz with a total of 1.6×10^{14} H^- ions delivered per pulse. Total available beam power from the linac at 8 GeV is thus 1.0 MW. The H^- ions are stripped at injection into the Recycler in a manner that "paints" the beam both transversely and longitudinally to reduce space charge forces. Following the 1.25 ms injection, the proton beam is moved off the stripping foil and is transferred in a single turn into the Main Injector. These protons are then accelerated to 120 GeV and fast extracted to a neutrino target. The 120 GeV Main Injector cycle takes 1.4 seconds, producing 2.1 MW of beam power. At lower proton energies Main Injector cycle times can be shorter. Since loading the Recycler requires only one linac beam pulse, the remaining linac cycles (six for a 1.4 sec MI cycle) are available for distribution of 8 GeV protons from the Recycler. Total available 8 GeV beam power can be maintained above 650 kW with Main Injector operations at ~2 MW for energies anywhere within the range 50-120 GeV.

Modifications to the Recycler Ring to support Project X include integration of an H^- injection system, a new RF system, a new extraction system, and measures to mitigate electron cloud effects. The Main Injector would need a new RF system, measures to preserve beam stability through transition, and measures to mitigate electron cloud effects.

The upgrade path to a high intensity beam supporting a possible future neutrino factory or a muon collider is the doubling the repetition rate and increasing the linac pulse length, with the potential to achieve a beam power of approximately 4 MW at 8 GeV. The linac hardware, conventional facilities, cryogenic plant, and utilities will be designed to accommodate these upgrades.

The RD&D plan is structured to capture the costs and labor efforts to bring the project from the ICD to a technical design report associated with the baseline schedule appropriate for a CD-2 decision. It matches the WBS for the cost range exercise associated with the CD-0 decision. There are 11 major elements in this structure.

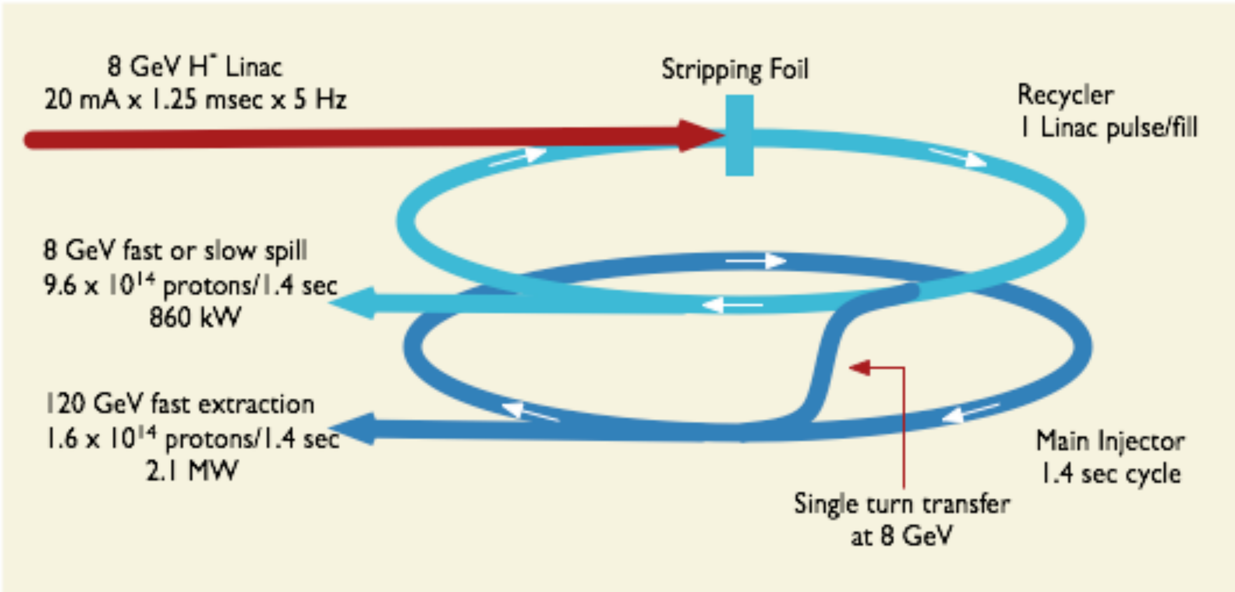

Figure I-1: Schematic View of Project X

The elements are as follows:

1. Project Management: capture cost and effort associated with the management of the project, including the preparation of documentation for the critical decision steps
2. LE linac: capture cost and effort associated with the design and development of the 325 MHz linac section that are not included in the HINS effort
3. HE linac: capture cost and effort associated with the design and development of the 1.3 GHz linac section that are specific to Project X and not included in the U.S. superconducting RF program
4. MI/RR: capture cost and effort associated with the design and development necessary to upgrade the Recycler Ring and the Main Injector for Project X requirements (does not include the injection system)
5. PX Instrumentation: capture cost and effort associated with the design and development of instrumentation for the linac, transfer line, and rings
6. Controls: capture cost and effort associated with the design and development of controls infrastructure
7. Cryogenics: capture cost and effort associated with the design and development of the cryogenic systems for the linacs and test areas, including cryo plants
8. Utilities & Interlocks: element of the construction phase, not directly the RD&D phase, included to match the cost range exercise structure
9. Conventional Facilities: capture cost and effort associated with design and development of the buildings, site work, and site utilities
10. 8 GeV: capture cost and effort associated with the design and development of the transfer line from the linac to the MI tunnel and for the injection system
11. Integration: capture cost and effort associated with the design and development of the accelerator design (across elements) and interfaces between elements

Chapter II describes assumptions on costs and labor input to the plan. Chapter III contains the descriptions of the RD&D plan elements.

II Input Assumptions

The information for each plan element is intended to capture the cost and labor associated just with that plan element, except for the Integration element. Integration captures the cost and labor associated with work that spans the other elements, with tasks in Physics Design, Interfaces, Optimization, and Coordination. For example, the linac lattice design spans the LE linac and the HE linac and the 8 GeV transfer line, so the cost and effort is captured in the Integration element.

The Project X linac stands to benefit from developments from other programs. The U.S. is investing significant resources in ongoing ILC, SRF, and HINS (High Intensity Neutrino Source) R&D programs. The U.S. effort on ILC is managed by the Americas Regional Team (ART) as part of the larger global effort being coordinated by the ILC/Global Design Effort (GDE). The SRF effort is building superconducting RF infrastructure at Fermilab and other U.S. laboratories that can be used to support the needs of ILC and other superconducting accelerator based efforts. Fermilab is responsible for coordination of the latter program. All of these programs share significant overlap with the technology requirements of Project X. Fermilab has adopted a strategy of maximizing alignment of technology performance parameters among the programs as a means for both providing maximally efficient utilization of existing resources while simultaneously providing maximum flexibility for the future.

These programs are all aiming for significant deliverables over the period 2010-2012. Goals and research plans for the ILC, SRF, and HINS programs are documented elsewhere, but summarized below. The GDE managed ILC program has developed a set of goals aimed at demonstrating a cost effective cryomodule design that meets ILC performance requirements. Responsibility for ILC cryomodule development is shared between Fermilab, Asian, and European institutions. The XFEL project at DESY, with production at a rate of roughly one/week starting in late 2011, is expected to provide critical input to the cryomodule design and production.

A goal of the Americas Regional Team (ART) managed U.S. program is to support the development of domestic capabilities for cavity fabrication, processing, and testing and the development of RF sources (centered at SLAC). The ART program directly supports the ILC cryomodule development goal (S1) through the design, construction, and testing, with U.S. industrial participation, of multiple ILC cryomodules and the operations of three of these cryomodules with beam at the ILCTC_NML test facility at Fermilab. This program is also supported by, and coordinated with, a domestic SRF program aimed at creating infrastructure to enable these goals. In particular, the U.S. SRF program is aimed at developing infrastructure sufficient to achieve a capability of producing cryomodules meeting the ILC operational specification at a rate of 12 cryomodules/year by 2012.

The goal of the HINS program is to demonstrate a new technological approach that could support the acceleration of high intensity, non-relativistic, H^- (and other ions).

The basic Project X development strategy is to carry a 1.3 GHz linac design compatible with an operating accelerating gradient in the range 25 MV/m to 31.5 MV/m through the conceptual design stage, and to select the final design gradient in advance of CD-2 based on the current state of development. In relation to HINS the strategy is to provide coordination between the programs, with a decision on whether to adopt HINS developed technologies for the Project X linac front end in advance of CD-2 based on consideration of cost, risk, and long term upgrade paths.

Project X assumes that the ILC, SRF and HINS funding programs supports the following deliverables:

- ILC
    - Three U.S. fabricated cryomodules, at least one is Project X prototype
- SRF Infrastructure:
    - Facilities capable of assembling 1 cryomodule/month
    - Test facility capable of testing a single ILC unit (3 cryomodules) with the ILC/PX beam current and pulse length, at 1 Hz repetition rate. (ILCTA_NML)
- HINS:
    - A 60 MeV front end H- linac capable of 27 mA x 3 ms operation based on superconducting spoke resonators and an RF distribution system utilizing ferrite vector modulators.

All estimates included in the plan elements work toward the goal of having a technical design report and baseline scheduled prepared for a CD-2 review in FY12. M&S costs are presented in FY09$ (no escalation) and labor in terms of FTEs. Although collaborations are encouraged and under discussion, for the purposes of this estimate all labor is assumed to be at FNAL, except in sections III.4 and III.10, where collaborators have already been identified. In these situations, collaborator labor has been included as M&S. Labor counts have been made for four general categories:

1. Scientist/Engineering Manager/IT Manager
2. Associate Scientist/Engineer/Accountant/Engineering Physicist/Computer Professional/ Budget Analyst
3. Machinist/Drafter/Lead Tech
4. Clerical/Technician/Operator

These categories are the same as those used in the CD-0 cost range exercise.

III Description of RD&D Plan elements

In this chapter, we describe each individual plan element. Included are the requirements, the technical issues and challenges associated with those requirements, the plan on how to address these issues, and a summary table of the cost and labor to meet the plan. In Table III-1, the summary over the period of FY09-FY12 is presented.

One aspect of the CD-0 to CD-1 process is the consideration of alternative configurations that meet the mission need defined at CD-0. In some cases, (e.g., 1.9 Conventional Facilities) we have included resources to address the consideration of alternatives. In other cases, (e.g., 1.7 Cryogenics and 1.10 8 GeV), we have not included such resources as the changes in scope associated with alternative configurations under consideration make it difficult to define the RD&D plan without a configuration document. The following discussion is therefore focused on the facility as described in the ICD.

Table III-1: RD&D Plan Summary

	FY09 $ and FTEs	FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1	**Project X RD&D**	$2,013	41.4	$9,531	67.9	$13,338	90.6	$10,281	101.7	$35,162	301.7
1.1	Project Management	$83	3.8	$415	8.0	$415	15.0	$415	19.0	$1,328	45.8
1.2	LE Linac	$0	0.3	$455	4.3	$700	9.0	$370	5.0	$1,525	18.5
1.3	HE Linac	$125	3.5	$650	8.5	$3,250	10.0	$1,350	10.0	$5,375	32.0
1.4	MI/RR	$446	10.0	$2,200	16.3	$1,420	19.4	$600	14.0	$4,666	59.7
1.5	PX Instrumentation	$235	5.4	$230	6.9	$215	6.9	$190	5.6	$870	24.8
1.6	Controls	$6	0.5	$40	7.6	$140	14.9	$75	16.1	$261	39.0
1.7	Cryogenics	$159	1.0	$370	3.0	$96	1.0	$0	1.0	$625	6.0
1.8	Utilities & Interlocks	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0
1.9	Conventional Facilities	$34	$135	$2,707	$1,575	$4,478	$1,700	$4,573	$1,620	$11,793	$5,030
1.10	8 GeV	$735	8.0	$804	7.3	$748	5.5	$593	4.6	$2,879	25.4
1.11	Integration	$55	9.1	$85	6.2	$175	9.0	$495	26.3	$810	50.6

III.1 Project Management

The Project Management element captures the cost and effort associated with management of the project prior to CD-2. M&S costs include travel (for project office staff and reviewers), computing, and training. Labor costs include project managers, engineers, controls and finances, and office staff. The costs (in FY09$ and FTEs) for project management are displayed in Table III-2.

The primary management goals are the formation of a multi-institutional collaboration to carry out the Project X RD&D program, the preparation of a plan for construction, and the development of all project documentation and organizational structures required by DOE Order 413.3. These goals are developed within an overall timeline as follows:

FY09

- Complete Initial Configuration Document (ICD)
- Form RD&D Collaboration
- Establish Project Management team
- Revise RD&D plan and initiate work
- Complete a preliminary cost estimate based on the ICD
- Complete Mission Needs Statement for CD-0
- Request PED funds for FY2011
- Initiate work on Conceptual Design Report

FY10

- Develop NEPA strategy
- Develop alternative implementations studies
- Initiate Environmental Assessment
- Initiate permitting documentation
- Draft of all CD-1 documentation, including CDR

FY11

- Achieve CD-1

- Complete EA and submit for review
- Initiate technical design
- Draft of all CD-2 documentation

FY12

- Receive FONSI for NEPA
- Continue technical design
- Complete all CD-2 documentation
- Achieve CD-2

The intention is to complete the Project X design and R&D with significant participation from outside of Fermilab, both in the organization and execution of the program. The goal is to form partnerships where collaborators have responsibility for complete and contained sub-projects.

Organization and Management Plan

The management organization for Project X from before CD-0 until CD-2/3a will support the establishment of a functional collaboration as well as support Fermilab efforts to create the full suite of project documentation and project management systems required under DOE Order 413.3 to meet the Critical Decisions. These latter efforts will include development of the resource-loaded schedule to a baseline in conjunction with a defensible cost estimate. In addition, various project documents will be created, including the Conceptual Design Report, Technical Design Report, Project Execution Plan, Project Management Plan, Risk Management Plan, Hazard Assessment, Configuration Management Plan, and NEPA documentation. Document management systems and websites will be created and maintained.

The Project Office will be established and staffed with Fermilab personnel to accomplish the management work, with the possibility of integration of collaborators into the Office. Functional roles will include project managers, project controls, technical managers, administrative support, and ES&H personnel.

Fermilab does not have the personnel resources to undertake the Project X RD&D Program, or a follow-on construction project, on its own. As such, the intention is to organize and execute the RD&D Program via a multi-institutional collaboration, drawing on significant participation from outside of Fermilab. The goal is to give collaborators complete and contained sub-projects, meaning they hold responsibility for design, engineering, estimating, and potentially construction if/when Project X proceeds. The general principles that we foresee being applied to the creation of the collaboration are outlined below.

Collaboration Structure

The Project X RD&D Collaboration will be established via a Collaboration Memorandum of Understanding (MOU) that will outline the basic goals of the collaboration, and the means of organizing and executing the work. Organizing principles for the collaboration are expected to include the following:

- Fermilab will hold responsibility for management of the RD&D Program for Project X. This includes appointment of the Project X Project Manager.
- The Project X Project Manager will hold overall responsibility for execution of the RD&D Program. This responsibility includes: organization and management of the Project X team; development of a reviewable/defensible accelerator physics and engineering design to achieve CD-2/3a, including identification of possible upgrade

paths; organization of a supporting R&D program; preparation of periodic progress reports; and development of a reviewable/defensible cost estimate and schedule for Project X construction.

- The Project Manager will be assisted in these responsibilities by a Project Team assembled by the Project Manager in consultation with the Fermilab Management and the Collaboration Council.
- A Collaboration Council will be established for the primary purpose of advising and assisting the Project Manager in the area of inter-laboratory coordination. The Collaboration Council will consist of representatives of the collaborating institutions.
- The Fermilab Directorate, in consultation with the Collaboration Council, will establish and receive technical advice from a Project X Technical Advisory Committee.
- Interactions between the collaboration members will be governed by a series of bi-lateral (or multi-lateral, where appropriate) MOU's. These MOU's will define specific division of labor between collaboration members, funding mechanisms, and associated deliverables.
- It is anticipated that the RD&D Program for Project X will be undertaken as a "national project with international participation". From the organizational perspective there is no distinguishing characteristic between national and international institutions, and so the expectation is that the same structure of MOU's described above would establish the participation of international laboratories.

Fermilab Internal Organization

Fermilab has established an internal organization for coordinated management of the Project X and ILC/SRF programs. Program organizations are established with reporting lines within the Fermilab Directorate via the Associate Director for Accelerators for Project X, and the ILC Program Director for ILC and associated SRF infrastructure. The Associate Director for Accelerators and the ILC Program Director are responsible for coordination of these activities. Within this organization, a single 1.3 GHz program has been created to support the needs of both ILC and Project X.

Table III-2: Project Management summary

	FY09 $ and FTEs										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.1	Project Management	$83	3.75	$415	8.00	$415	15.00	$415	19.00	$1,328	45.75
1.1.1	CD-0 to CD-1	$83	3.75	$415	8.00	$40	2.50	$0	0.00	$538	14.25
1.1.2	CD-1 to CD-2	$0	0.00	$0	0.00	$375	12.50	$280	13.25	$655	25.75
1.1.3	CD-2 to CD-3	$0	0.00	$0	0.00	$0	0.00	$135	5.75	$135	5.75
1.1.4	CD-3 to CD-4	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.00

III.2 LE linac

The Low Energy (325 MHz) linac comprises the front end of the proposed 8 GeV Project X linac; it includes the ion source and the entire accelerator upstream of the 1.3 GHz cavity cryomodules. It is expected that many technologies and components applicable to the Low Energy linac are developed under the High Intensity Neutrino Source (HINS) RD&D program that has been ongoing since FY06. The technology selection for the Project X Low Energy linac is an early element of the Project X RD&D effort. This RD&D plan, written with the assumption that HINS technology is employed for Project X as written in the Project X ICD, includes only items beyond the scope of or not completely developed by HINS. As a result, Table III-3 shows only the work outside the HINS scope, while preserving the full structure of the cost exercise (which is why lines 1.2.2-1.2.6 are zero). If an alternate technology is selected or should the HINS effort reveal technical show-stoppers or terminate prematurely, the Project X RD&D plan must be changed accordingly.

LE linac Requirements

The Low Energy linac is required to deliver 1.25 millisecond pulses of 1.6 x 10^{14} H^- ions at 420 MeV and at pulse rates up to 5 Hz. The output beam must present transverse emittance and longitudinal bunch parameters as required by the 1.3 GHz High Energy linac. The 1.25 millisecond pulse must incorporate a Recycler RF bucket frequency structure to facilitate pseudo buncH-to-bucket transfer as well as a Recycler revolution frequency structure to provide a 700 nanosecond abort/extraction gap in the Recycler ring. The Low Energy linac is required to have 98% availability.

LE linac Issues

The issues raised by the requirements for the Low Energy linac are technological, engineering, and cost-benefit issues; no new accelerator physics issues are posed by a 420 MeV, 1.6 x 10^{14} particles per pulse, 5 Hz, H^- linac. Completing a comprehensive, practical end-to-end accelerator physics design for the combined Low and High Energy linac is the job number one. For the Low Energy linac, this includes selection of an engineering technology that is cost effective and yet sufficiently flexible to allow an upgrade path.

Assuming the HINS technology is adopted, the critical Low Energy linac components falling outside the scope of the HINS program are the ion source and the superconducting single-spoke $\beta = 0.4$ (SSR2) and triple-spoke $\beta = 0.6$ (TSR) accelerating cavities and their respective cryomodules. The beam duty cycle and machine availability requirements push the envelope of any existing H^- ion source; development in this area is necessary and indicates collaborative efforts with SNS ion source efforts. The superconducting spoke cavities and cryomodules must be designed, prototyped, constructed, tested, and characterized within the Project X RD&D effort. RF power distribution and control for the 325 MHz SSR2 and TSR systems also require development, since the power levels are higher than encountered in the HINS program. Beam diagnostics for the SSR2 and TSR sections, otherwise outside the scope of HINS, must also be developed.

Assumptions

The Low Energy linac RD&D for Project X assumes completion of the HINS R&D program consisting of a 30 MeV, 325 MHz superconducting demonstration linac constructed in the Meson Detector Building by the end of 2012. It assumes that the SRF infrastructure and skills base provided for HINS as well as the 325 MHz SRF facilities used by HINS remain available for Project X RD&D; Project X covers only the incremental costs. It assumes that "partner Labs" collaborate in Project X RD&D activities and includes the partner lab effort in estimates here as well as the local effort to organize and coordinate the collaborative tasks.

The timeframe for Project X Low Energy linac RD&D described here (separate from HINS) assumes that it is completed in FY12 to support Project X CD-2 baseline in that year.

LE linac Plan Elements

Physics Design

This element is the effort to establish the physics design of the Low Energy linac as part of the comprehensive Project X linac design meeting the top-level Project X beam requirements of energy, intensity, emittance, and temporal structure. The Low Energy effort will help establish and must then satisfy the beam interface requirements to the High Energy linac. Additionally, requirements for operational availability, acceptable beam losses, and radiation shielding must be considered. Specifications must be established for beam measurements and diagnostics systems to validate performance and facilitate operation. The basic physics design must be completed in FY10 so that accelerator system requirements are available to establish a basis for beginning system designs. Ongoing physics integration support will be required throughout the Project X RD&D effort. The cost and effort for this task is captured in section III.11, in line 1.11.1.

A specific task within this WBS element is a technology study to determine whether the HINS design or an alternative is adopted for the Project X front-end. This is a cost-benefit study requiring accelerator physics and engineering effort. This task is closely coupled to the comprehensive Project X linac physics design and must be accomplished on a similar time scale to set the foundation and direction for required RD&D.

- **Deliverable** – participation in the comprehensive Project X linac accelerator physics design.
- **Deliverable** – documented and justified decision on physics approach to design of beam accelerating structures and focusing elements to meet Project X Low Energy linac requirements.
- **Deliverable** – CD-1 and CD-2 level physics design of Low Energy linac, specification of sub-system requirements, interface and integration specifications, documentation, and cost estimates for linac to meet Project X Low Energy linac requirements.

Ion Source

This task is to develop, prototype and test an H^- ion source with required emittance, beam current, pulse length, and duty cycle and operational lifetime for the Project X linac. Low energy beam diagnostic equipment to measure and verify source beam parameters, including and especially emittance, are included.

- **Deliverable** – tested and documented design of ion source to meet Project X Low Energy linac requirements.

SSR2 and TSR Cavities and Cryomodules

The tasks in this element develop the single-spoke SSR2 and triple-spoke TSR superconducting 325 MHz cavity designs, processes, and cryomodules. Two prototype cavities of each with helium vessels, power couplers, and slow and fast tuners will be constructed. Mechanical, vacuum, cryogenic, low level RF, and high RF power testing is done. Measurements of Lorentz de-tuning under full, pulsed RF power conditions are made. Design of the respective cryomodules is also included.

- **Deliverable** – documented design and working prototype of SSR2 and TSR cavities with helium vessels, power couplers, and tuners to meet Project X Low Energy linac requirements.
- **Deliverable** – documented design of SSR2 and TSR cryomodules meeting Project X Low Energy linac requirements.

Finally, this element includes the systems integration and interface development effort required for the SSR2 and TSR cavities and cryomodules. The cost and effort for this task are captured in lines 1.11.2 of Table III-12.

- **Deliverable** – CD-1 and CD-2 level technical specifications, interface and integration specifications, documentation, and cost estimates for SSR2 and TST cavity and cryomodule systems to meet Project X Low Energy linac requirements.

Low Energy linac RF Systems

This element includes an engineering and beam physics study to determine cost vs. benefit of the "one klystron, many cavity" design approach used in the HINS design.

- **Deliverable** – documented and justified decision on approach to supply of 325 MHz RF power to the accelerating structures to meet Project X Low Energy linac requirements.

A second effort in this element is to develop and design the selected 325 MHz RF power distribution system for the 325 MHz section of the linac, including vector modulators of suitable power handling capability. Components will be developed and prototyped. Testing at low and high RF power levels will be done.

- **Deliverable** – verified and documented design with prototypes of 325 MHz RF power distribution system including vector modulators with prototypes as necessary to meet Project X Low Energy linac requirements.

This element also includes development of the low-level RF system beyond that accomplished by the HINS R&D effort for the entire 325 MHz Low Energy linac. Hardware and software components, including RF reference signal distribution, will be specified, developed, simulated, prototyped, and tested.

- **Deliverable** – tested and documented design of 325 MHz low level RF system to meet Project X Low Energy linac requirements.

Finally, this element includes the systems integration and interface development effort required for the entire Low Energy linac 325 MHz RF system.

- **Deliverable** – CD-1 and CD-2 level technical specifications, interface and integration specifications, documentation, and cost estimates for RF power, RF power distribution, and RF control systems to meet Project X Low Energy linac requirements.

Magnets Systems

Hardware prototyping RD&D for focusing and steering magnets and power supply systems integration is not expected. Activity in these elements is primarily the development of system and sub-systems requirements. This includes technical, interface and integration specifications, CD-1 and CD-2 level documentation, and cost estimates for beam line magnets and power supply systems, magnet cryogenics systems, and controls systems to meet Project X Low Energy linac requirements.

- **Deliverable** – CD-1 and CD-2 level technical specifications, interface and integration specifications, documentation, and cost estimates for beam line magnets and power supply systems to meet Project X Low Energy linac requirements.

LE linac Schedule

The basic accelerator physics design and the HINS vs. alternative technology study will begin in FY09.

Machine design and technology decisions will be completed in FY10. Ion source development, triple-spoke cavity electromagnetic and mechanical design and material procurement, low-level RF development and systems integration efforts for other Low Energy linac accelerator systems will begin in FY10. SSR2 and TSR design efforts must begin in FY10.

Ion source prototyping and testing continues in FY11. Spoke cavity prototype fabrication, vector modulator and RF distribution system development, and beam instrumentation prototype design and fabrication begin in this year. Efforts are applied to produce required CD-1 documentation and review materials for all systems in early FY11.

FY12 brings the completion of fabrication and processing and the start of testing of the SSR2 and TSR cavities in the HINS test cryostat. Ion source development, RF power distribution system design, and beam instrumentation prototyping will climax in FY12. Final CD-2 level documentation, cost estimates, and review preparations for all LEL systems is produced in this year.

Table III-3: LE linac summary

	FY09 $ and FTEs										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Lab
1.2	LE Linac	$0	0.25	$455	4.25	$700	9.00	$370	5.00	$1,525	18.5
1.2.1	Ion Source & LEBT	$0	0.00	$60	1.25	$150	2.25	$50	1.00	$260	4.5
1.2.2	RF Quad	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.2.3	Beam Diagnostics (covered below)	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.2.4	MEBT	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.2.5	Room Temperature Section	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.2.6	SSR1 Cryomodules	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.2.7	SSR2 Cryomodules	$0	0.00	$160	0.88	$213	1.63	$75	1.13	$448	3.6
1.2.8	TSR Cryomodules	$0	0.00	$160	0.88	$213	1.63	$75	1.13	$448	3.6
1.2.9	325 MHz RF and Distribution	$0	0.25	$38	0.63	$63	1.75	$85	0.88	$185	3.5
1.2.10	325MHz LLRF	$0	0.00	$38	0.63	$63	1.75	$85	0.88	$185	3.2

III.3 HE linac

The High Energy linac is an ILC-like 8 GeV, 1 MW linac that provides a beam current of 20 mA with a pulse length of 1.25 ms and a repetition rate of 5 Hz. It is designed to accelerate H- ions from 0.42 GeV to 8 GeV, preserving the micro and macro bunch structure created in the LE linac, utilizing superconducting RF cavities at 1300 MHz.

HE linac Requirements

The HE linac consists of two distinct parts: β=0.81 cryomodules from 0.42 to 1.2 GeV and β=1.0 cryomodules from 1.2 to 8 GeV. The development of the β=0.81 cavities and cryomodules is Project X specific and will comprise a significant portion of the linac RD&D program, whereas the β=1.0 cavities and cryomodules are being developed under the auspices of the ILC R&D program. The development of fast high-power phase shifters and RF power couplers are additional significant linac RD&D activities.

The proposed RD&D program is designed to specifically address the primary technical requirements defined in the ICD and to verify design choices.

HE linac Plan

Major goals of the HE linac RD&D program include:

- Develop, procure and test (without beam) in FY12 a single β=0.81 cryomodule prototype
- Develop, procure and test (with beam) in FY12 a RF unit (2-3 cryomodules powered by single klystron)
- Develop, procure and test in FY11 a prototype for the RF distribution system with fast phase-shifters
- Develop, procure and test in FY10 prototype RF power couplers capable of achieving the Project X upgrade parameters (Table 4)
- Carry out simulations and measurements in FY09-10 to understand the Higher Order Mode (HOM) damping requirements
- Complete a conceptual design report in FY10.
- Initialize industrialization activities for linac components in FY10
- Improve Project X cost estimate by prototyping critical technical elements in FY11

Linac Technical Design

Cryomodule Mechanical and Cryogenic Design

The design basis for the HE linac cryomodules is the Fermilab ILC Type-4 cryomodule, which is derived from the European XFEL cryomodule design. The Type-4 cryomodule consists of eight cavities plus a center-mounted quadrupole package and beam position monitor (BPM). The following issues must be addressed in designing the cryomodules:

- Determine whether or not the 5 K thermal shield is needed
- Determine whether or not the existing cold-mass pipe sizes are appropriate
- Determine the cavity tuner type and position
- Determine the final coupler design interfaces
- Determine static and dynamic heat loads for baseline and upgrade parameters
- Evaluate stainless steel design of cavity helium vessels and two-phase transfer pipes
- Perform value engineering to reduce manufacturing costs and/or improve performance

This work will be conducted at Fermilab.

Design of the β =0.81 Cavities and Cryomodules

The β =0.81 cryomodule design will be based on the Fermilab ILC Type-4 cryomodule. It is intended that the β =0.81 and β =1.0 cryomodules be very similar in design, and that many cryomodule components can be shared between the two cryomodules. Hence development time and production costs will be minimized.

The β =0.81 cavity has been prototyped at Michigan State University (MSU). Two single-cell cavities have been fabricated, processed and tested. Two 7-cell cavities have also been fabricated: one from fine-grain niobium, the other from large-grain niobium. These cavities have simple beam tubes without HOM couplers and RF ports. These cavities will be processed and tested in FY09-10.

The cavity design must be optimized with respect to the following parameters:

- Number of cells
- Cell geometry and cell-to-cell coupling
- HOM spectrum and damping requirements
- Multipacting
- Integration with Type-4 cryomodule design

This work will be conducted collaboratively between Fermilab, MSU and Indian Institutions.

Table III-4: Upgrade requirements for the HE linac -- impact on RF coupler performance

Parameters	Units	1 MW	2 MW Upgrade	4 MW Upgrade
Beam energy	GeV	8	8	8
Current	mA	20	20	20
Repetition rate	Hz	5	10	10
Acc. Gradient (beta=1)	MV/m	25	25	25
Q external	10^6	1.25	1.25	1.25
Filling time	ms	0.212	0.212	0.212
Pulse length (flat-top)	ms	1.25	1.25	2.5
Total RF pulse length	ms	1.465	1.465	2.712
Peak power / coupler	**kW**	**500**	**500**	**500**
Average power / coupler	**kW**	**3.7**	**7.3**	**13.6**

RF Coupler Design and Prototyping

The RF coupler requirements are described in Table III-4 for the baseline 1 MW linac configuration and for 2 MW and 4 MW upgrade scenarios. The existing TTF-3 coupler design is a good starting point since it is a proven component of the European XFEL cryomodule design. However, Project X requires higher peak and average power transmission compared to the XFEL project. Peak power transmission will be 500 kW with average power transmission ranging from 3.7 to 13.6 kW for the linac beam power range 1 to 4 MW. The peak power requirement does not increase with beam power.

The TTF-3 coupler may meet the peak power requirements, but cannot meet the average power requirements. Therefore the following RD&D activities are planned:

- Perform testing of TTF-3 couplers to investigate multipacting behavior and conditioning time for 500 kW peak power operation
- Explore possible benefit – with respect to multipacting – of increasing the coupler cold-part diameter to 60 mm
- Develop design modifications that can increase average power capabilities to match Project X requirements
- Build and test prototype couplers

This work will be conducted collaboratively between Fermilab and SLAC.

Magnets

The cryomodule magnet packages will be designed, fabricated and tested in accordance with the beam physics requirements. These magnet packages will be installed in the β=1.0 cryomodules 2-4 in the FY09-FY12 period, and will be installed in the prototype β=0.81 cryomodule in FY12. This work will be conducted at Fermilab.

RF Power Systems

Klystrons

The baseline configuration calls for one 10 MW multi-beam klystron per two cryomodules. Another possible configuration is one 5 MW single-beam klystron per cryomodule. The choice will depend on costs and upgrade strategy. The power upgrade plan calls for doubling the repetition rate and pulse length. This increase in required average power could lead to the one klystron per cryomodule configuration. The RD&D plan includes the following activities:

- Long-term testing of 10 MW multi-beam klystrons at SLAC as part of the ILC R&D program
- Installation and operation of 5 MW and 10 MW klystrons at the Fermilab NML facility for the purposes of cryomodule and RF unit tests
- Evaluation of klystron requirements and capabilities under various power upgrade scenarios, including possible changes in pulse length and linac beam current
- Discussions with klystron vendors regarding options for increased average power

This work will be conducted collaboratively between Fermilab and SLAC.

Modulators

The baseline configuration calls for the proven Fermilab "bouncer" type modulator and pulse transformer. A possible alternative is the Marx modulator being developed at SLAC. The Marx modulator does not require a pulse transformer and is perhaps less expensive compared to the bouncer modulator. However, it is still in the early developmental stages and may not be ready in time for Project X. The Marx modulator R&D is being supported as part of the ILC R&D program. Several bouncer-type modulators will be fabricated and operated at Fermilab in support of the HINS and NML programs during the Project X RD&D period. All of these activities will be funded outside of Project X. These activities will be conducted collaboratively between Fermilab and SLAC.

Distribution system

The RF distribution system connects the klystrons to the RF couplers on the cryomodules. The NML RF distribution system has been developed and provided by SLAC as part of the ILC R&D program. This will continue throughout the Project X RD&D period as more cryomodules are installed in NML. Through this experience, the optimal distribution system for Project X will be determined based on cost and performance considerations. This work will be conducted collaboratively between Fermilab and SLAC.

Fast phase shifters

Fast high-power phase shifters are needed to control the cavity fields since it is planned to power multiple cavities per klystron. This is important not only for normal operations, but also to allow continued operation of the linac in the case of individual cavity failures. The phase shifters must be fast enough to at least allow pulse-to-pulse corrections. Ideally they will have sufficiently high bandwidth to allow intra-pulse corrections. RD&D activities include design, prototyping, and testing of these phase shifters in cooperation with industry where possible. These activities will be conducted collaboratively between Fermilab and SLAC.

Interfaces to Other Systems

The HE linac includes numerous interfaces to other subsystems and WBS elements. While these subsystems are not within the scope of the HE linac work package (they are captured in element III.11 Integration), it is imperative that the interfaces to these subsystems are carefully considered and planned during the Project X RD&D period. The primary activities will include:

- Participation in integration meetings.
- Reviewing of plans, requirements and designs for related subsystems.
- Preparation of linac requirements placed on related subsystems.
- Documentation of interfaces to the HE linac.

These activities will be conducted primarily at Fermilab.

Conventional Facilities

- Participate in linac-specific civil construction RD&D activities.
- Provide requirements for linac technical components.

Utilities

- Participate in linac-specific utilities design RD&D activities.
- Provide requirements for linac technical components.

Cryogenic System

- Provide cryomodule cooling requirements.
- Provide cryogenic system segmentation requirements based on linac maintenance requirements.

Vacuum System

- Provide requirements for linac vacuum systems including beam line vacuum, coupler vacuum, and cryomodule insulating vacuum.

Low Level RF Control System

- Provide linac-specific LLRF requirements.

Instrumentation

- Provide requirements for instrumentation that will be installed in 1300 MHz cryomodules.

Control System

- Provide linac-specific control system requirements.

Machine Protection System

- Develop integrated linac-specific machine protection requirements.

Other Activities

Failure Mitigation

- Consider linac component failure scenarios and devise strategies for mitigating the effects of these failures.
- Develop plan for maintaining and repairing radioactive linac components.

Installation

- Develop linac installation plan including cost and schedule.

HE linac Schedule

The HE linac work is strongly coupled to the U.S. ILC/SRF program. The schedule and plan for the Project X work is in parallel with the schedule of the cryomodule development. In the list below, we include the work from these two programs and identify which program is responsible.

FY09

- Project X
    - RF coupler design studies
    - HOM studies
    - β=0.81 cavity design studies
    - Processing and testing of prototype β=0.81 cavities at MSU
    - Begin design of β=0.81 cryomodule
    - Test prototype phase shifter produced by industry (AFT)
    - Continue work on fast phase shifter design in collaboration with industry
- ILC/SRF Program
    - RF coupler (TTF-3) testing at SLAC
    - Modulator and klystron testing at SLAC
    - Modulator and klystron operation at Fermilab
    - Test of β=1.0 cryomodule #1 at Fermilab
    - Completion of Type-4 cryomodule design
    - Fabricate, test and install quadrupole package for β=1.0 cryomodule #1
    - Test prototype RF distribution with β=1.0 cryomodule #1

FY10

- Project X
    - Complete HOM studies
    - Order β=0.81 prototype cavities from industry (with HOM couplers and RF ports)
    - Complete conceptual design report

- Fabricate and test prototype RF couplers
    - Develop linac installation plans
    - Fabricate and test fast phase shifters
- ILC/SRF
    - Fabricate, test and install quadrupole package for β=1.0 cryomodule #2
    - Complete fabrication of β=1.0 cryomodule #2
    - Continue modulator and klystron testing
    - Fabricate additional RF distribution systems for use at NML
    - Test β=1.0 cryomodule #2

FY11

- Project X
    - Procure and test industrially produced fast phase shifters
    - Process and test industrially produced β=0.81 prototype cavities
    - Dress and horizontally test β=0.81 prototype cavities
    - Order β=0.81 "production" cavities from industry
    - Order RF couplers for installation on β=1.0 cryomodule #3 and β=0.81 prototype cryomodule; begin RF testing and conditioning of these couplers
- ILC/SRF
    - Fabricate, test and install quadrupole package for β=1.0 cryomodule #3
    - Complete fabrication of β=1.0 cryomodule #3
    - Test β=1.0 cryomodule #3

FY12

- Project X
    - Process and test β=0.81 "production" cavities
    - Fabricate, test and install quadrupole package for β=0.81 prototype cryomodule
    - Complete fabrication of β=0.81 prototype cryomodule
    - Test β=0.81 prototype cryomodule
    - Finalize linac design and prepare for construction
- ILC/SRF
    - Fabricate, test and install quadrupole package for β=1.0 cryomodule #4
    - Complete fabrication of β=1.0 cryomodule #4
    - Test β=1.0 cryomodule #4
    - Perform RF unit test

Table III-5: HE linac Summary

	FY09 $ and FTEs										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.3	HE Linac	$125	3.50	$650	8.50	$3,250	10.00	$1,350	10.00	$5,375	32.00
1.3.1	Beta = 0.81 Cryomodules	$125	2.00	$500	4.00	$2,500	7.00	$1,000	8.00	$4,125	21.00
1.3.2	Beta = 1.0 Cryomodules	$0	0.00	$0	1.00	$0	0.00	$0	0.00	$0	1.00
1.3.3	Debuncher Beta = 1.0 (copper) Ca	$0	0.50	$0	0.50	$0	0.00	$0	0.00	$0	1.00
1.3.4	1.3 GHz RF and Distribution	$0	0.75	$100	2.00	$500	2.00	$100	1.00	$700	5.75
1.3.5	1.3GHz LLRF and Global LLRF Syst	$0	0.25	$50	1.00	$250	1.00	$250	1.00	$550	3.25

III.4 MI/RR

The Fermilab Recycler is a fixed energy 8 GeV storage ring using strontium ferrite permanent magnets in the Main Injector tunnel. The Main Injector is a rapid cycling synchrotron with a maximum energy of 150 GeV. For Project X, the Recycler will operate as a stripping ring and a proton accumulator, taking a single pulse from the linac, capturing the beam in 53 MHz RF buckets, and performing a single turn injection into the Main Injector. The injection and stripping systems are described in Section III.10. The Main Injector will receive 1.6×10^{14} protons from the Recycler in a single turn and will accelerate them to 120 GeV in 1.4 seconds. This is about 3.5 the beam intensity Main Injector will be required to accelerate for the Nova program. The RD&D plan presented in this document assumes that the upgrades in the Nova program are being carried out. A summary of MI/RR cost and effort is shown in Table III-6.

MI/RR Requirements

The most demanding requirements for both rings are the peak beam current of 2.4 A and the maximum space charge tune shift of 0.05. These requirements drive the plan for the injection painting system to achieve a K-V transverse distribution (which is discussed in Section III.10). The beam current requirements lead to significant questions regarding electron cloud generation and mitigation. For both rings, the beam power along with the bunching factor drive the RF system design. The beam current requirements along with the bunch spacing raise questions about electron cloud instabilities. For the MI, a high acceleration efficiency requirement leads to questions about controlling the transition crossing.

MI/RR Issues

With a new injection insert in the Recycler Ring, we anticipate that we may need more flexibility in the lattice design. The Recycler is built with permanent magnet dipoles, permanent magnet combined function devices, powered dipole correctors, and a tune trombone of powered quadrupoles. RD&D effort on lattice design and magnet / power supply design is included to allow this flexibility.

The maximum peak current required assumes 3 times the protons per 53MHz bunch in Main Injector than the current operation. Electron cloud instabilities could be a limitation to the maximum MI intensity as in the Recycler. Currently in MI with 1E11 particles per 53MHz bunch electron cloud is not a problem because the bunch intensity is below the threshold.

The current Main Injector RF system does not have the power to accelerate the required beam intensity to 120 GeV in 1.4 seconds (even with the addition of a second power tube per station). To achieve the required bunching factor a substantial second harmonic RF system will be needed. Finally there is a possibility of changing the RF frequency because of electron cloud issues.

We expect that the Nova era Main Injector and Recycler dampers will be able with some modifications to damp most of the other instabilities. Crossing transition without beam loss will require a γ_t jump.

MI/RR Plan

The RD&D plan for the Recycler Ring and Main Injector consists of elements for physics design questions (lattice & optics, electron cloud instability mitigation, transition crossing), magnet and power supply design, and RF design. Most of these elements cover development in areas where we are knowledgeable about the generalities (e.g., lattice design) but need to invest scientific and engineering time in the specifics (e.g., magnet specification, construction, and installation). A joint program covering e-cloud issues in MI and Recycler, including simulations and measurements, will be undertaken to develop a better understanding of the generation of electron cloud and the dependence on various parameters (SEY, bunch spacing, intensity, RF frequency etc.). The possibility of coating of the MI/RR beam pipes will be investigated.

MI/RR Schedule

FY09

- Lattice Design work for Recycler begins
- New MI RF system: Optimize the existing 53MHz cavity design and draw out the HLRF system architecture. Start initial paper design of a second harmonic cavity. Initiate design for a higher fundamental frequency cavity.
- Electron Cloud: Run simulations for e-cloud in MI using two different programs (POSINST, ECLOUD). Compare the effects of smaller SEY and higher RF frequencies. Continue the e-cloud measurements in MI using the existing detector and including the EM wave propagation method. Coat 4 beam tubes (in collaboration with BNL); install one in MI during 2009 summer shutdown. Start work with SLAC on TiN coating.

FY10

- Complete Lattice Design for Recycler
- Magnet and Power Supply Design for new Recycler lattice
- New MI RF system: Select the new RF frequency. Finalize the cavity and tuner design. Schedule cavity design review. Start ordering major components for construction of a prototype cavity and tuner. Finish second harmonic cavity design.
- Electron Cloud: Continue the e-cloud simulations and comparisons to measurements in MI.

FY11

- Requirements for Instrumentation in both MI and RR complete
- New MI RF system: Finish assembling prototype cavity and tuner and start low level testing. Schedule second harmonic cavity review and order parts for a prototype cavity.
- Electron Cloud: Continue and refine the e-cloud simulations. Include beam dynamic effects. Coat two MI dipoles in a service building and evaluate the results.

FY12

- Finalize Magnet and Power supply requirements for new Recycler lattice
- Finalize Instrumentation requirements
- New MI RF system: Finish high power cavity testing in test station. Plan to install in MI tunnel for testing. High power test second harmonic cavity in test station.

- Electron Cloud: Formulate a concrete plan for the e-cloud problem and have a review to evaluate it.

Table III-6: MI/RR Summary

	FY09 $ and FTEs	FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Lab
1.40	MI/RR	$446	10.00	$2,200	16.25	$1,420	19.40	$600	14.00	$4,666	59.
1.4.1	High Level RF Systems MI	$220	0.00	$1,750	0.00	$1,020	0.00	$350	0.00	$3,340	0.0
1.4.2	High Level RF System RR	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.4.3	Installation Costs	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.4.4	MI/RR RF Labor	$0	3.60	$0	8.60	$0	11.10	$0	4.75	$0	28.
1.4.5	Gamma-t Jump	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.0
1.4.6	Recycler Modifications	$0	1.75	$150	4.25	$150	4.25	$150	4.25	$450	14.
1.4.7	Physics Design & Modelling	$226	4.65	$300	3.40	$250	4.05	$100	5.00	$876	17.

III.5 PX Instrumentation

Beam instrumentation and diagnostic systems are used throughout the entire accelerator complex to measure, characterize and verify all Project X beam parameters. For machine commissioning, a minimum set of diagnostic systems has to be available to observe:

- Beam intensity
- Beam positions, beam orbit
- Transverse beam profiles, beam emittance
- Beam phase, timing

Moreover, a reliable beam loss monitoring (BLM) system is mandatory, as part of an integrated machine protection system (MPS) to prevent quenches in cryogenic sections or damage by the high-intensity beam.

Besides the basic beam instruments, a variety of more sophisticated diagnostic tools is required to ensure, and improve the beam quality, e.g. minimize beam losses due to longitudinal bunch "tails". A crucial point in the RD&D phase of Project X is the development of non-invasive beam diagnostics, to minimize the impact of the high intensity beam on the instrument (survival), and the scattering effects (background) of invasive beam detection methods. At the Main Injector ring accelerator, the high intensity, high power proton beam causes additional problems due to electron-cloud instabilities. Therefore, a permanent e-cloud monitoring system has to be integrated.

The scope of beam instrumentation hardware includes:

- EM or optical beam detectors / pickups (often are part of the vacuum system) and control elements (motors, switches, etc.).
- Read-out, analysis and calibration electronics, and related hardware.
- Infrastructure, e.g. cabling, timing and clock systems, racks, crates, power supplies, DAQ / controls interface.

A summary of the RD&D costs and effort for PX instrumentation is shown in Table III-7.

Instrumentation Requirements

A detailed analysis of the requirements for each beam instrumentation system is actually part of the RD&D plan, and has to be studied along with beam dynamics simulations and particle tracking. At this stage we can only set some preliminary general requirements for some parts of the beam instrumentation systems.

Beam intensity measurements will require a linearity in the 1...3 % range. Low intensity beams, including short beam pulse operation (~100 μsec) during machine commissioning or beam studies, have to be monitored as well as the high intensity beams, including upgrade scenarios of up to 30 mA and 3 msec pulse length. Toroids have to be able to time resolve the beam intensity within 100 μsec. In the case they are part of the machine protection system (MPS) the differential errors, linearity, etc. between pairs has to be << 1 %. A non-invasive broadband current monitor (e.g. wall current monitor) has to be incorporated to study the chopper efficiency and timing.

Beam position monitors (BPM) are used for a great variety of beam measurements, including beam commissioning and troubleshooting. Similar to the beam intensity measurement systems, they require a sufficient dynamic range for low and high intensity beam operation. The position resolution should be a fraction (~0.3...0.5) of the transverse RMS beam size. A time resolution of individual bunches is not required; however, as for most diagnostic systems, the measurement (integration) time has to be short enough to handle a short beam pulse of ~100 μsec. Many BPM detectors have to be located inside cryogenic sections (so-called cold BPMs). This gives additional requirements in terms of clean room class 100 certification (because of the proximity of the SRF accelerating structures), and operation at low temperatures (~4 K).

The characterization of the transverse beam *emittance* is one of the crucial beam measurements, required to enable high quality beam operation. Different styles of beam profile monitors, including non-invasive types (e.g. laser wire, e-beam scanner), will be involved for this characterization. Invasive beam profile monitors (wire scanners, multiwires / harps) cannot be installed close to SRF sections, as they may pollute and damage the SC environment.

For RF and beam commissioning the measurement of the *beam phase*, or time-of-flight will be of great value. We are planning to make use of the BPMs and the availability of a phase signal in the digital signal processing, which has to provide a $<1^0$ phase resolution.

Other requirements include the use of BLM detector for the MPS system, the measurement of beam halo and tails, as well as system integration and standardization, data acquisition and time stamping of data to perform correlation analysis and troubleshooting.

Instrumentation Issues

The most important issues addressed by the RD&D plan:

- Design and development of prototypes for the mission critical beam diagnostics systems
- Gaining practical experience with beam studies at the HINS test accelerator and the Main Injector
- Readiness for production quantities of all Project X beam instrumentation systems
- Deliver a complete set of CD-2 level technical specifications, documentation and cost estimation for each beam instrumentation subsystem, including physical and logical integration definitions

Instrumentation Plan

The RD&D plan for Instrumentation focuses on mission critical diagnostics with stringent, hard to meet requirements. Test beds are the HINS test accelerator and the Main Injector and - if the circumstances allow - we also will perform beam tests at accelerators of collaborating laboratories, e.g. SNS. The RD&D plan lists the following diagnostic systems to be developed and studied over a 4 year period (until CD-2 in FY12):

- Injection thru 325 MHz
    - Allison scanner: Emittance monitor for the LEBT, in collaboration with ORNL/SNS
    - Multiwire / slit: Dedicated MEBT emittance monitor tank, in collaboration with ORNL/SNS
    - Improvements and modifications on existing wire scanners for the transverse beam profile (MEBT)
    - Development of OTR screen monitors for transverse beam profile measurements
    - Development of non-invasive (fiber) laser-based diagnostics, in collaboration with LBNL
    - Development of a higH-power fast Faraday cup for bunch length monitoring, in collaboration with ORNL/SNS
    - Development of beam halo diagnostics, e.g. a vibrating wire monitor
    - Development of a cold stripline BPM
- 1.3 GHz thru Main Injector
    - Development of a non-invasive e-beam scanner as a transverse beam profile monitor, in collaboration with ORNL/SNS
    - Further development, improvements and modifications on IPM diagnostics for the Main Injector
    - Development and beam studies with microwave transmission e-cloud diagnostics.
    - Design of a cold BPM for the 1.3 GHz cryomodule

For these developments, a total of $870k in M&S in foreseen, to be spend over a period of 4 years (CD-0 to CD-2). We estimate the need of 5 to 7 FTEs per year (of four categories) to support this plan. We also included funds for travel, coordination, and management, for laboratory equipment (commercial measurement equipment, development tools, software, etc.), and for related hard-and firmware (analog electronics, digital signal processing systems, etc.).

Beside the technical developments and beam studies, we need to work out a list of complete specifications for each of the beam instrumentation systems, based on the requirements set by beam dynamics studies and the available real estate.

Instrumentation Schedule

FY09

- Requirements and specifications for each beam instrument
- Start: Multiwire/slit, fast Faraday cup, e-beam scanner
- Continue: Laser-based diagnostics, IPM, e-cloud diagnostics, cold BPM

FY10

- Start: Allison scanner, wire scanner improvements, screen monitors, beam halo diagnostics

- Finalize: e-cloud diagnostics, cold BPM
- Continue: everything else

FY11

- Finalize: IPM, fast Faraday cup
- Continue: everything else

FY12

- Finalize: everything!
- CD-2 level technical specifications, documentation and cost estimates

Table III-7: PX Instrumentation Summary

	FY09 $ and FTEs										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.5	PX Instrumentation	$235	5.38	$230	6.88	$215	6.88	$190	5.63	$870	24.75
1.5.1	Injection thru 325 Mhz	$95	0.00	$145	0.00	$165	0.00	$120	0.00	$525	0.00
1.5.2	1.3 Ghz thru MI	$140	0.00	$85	0.00	$50	0.00	$70	0.00	$345	0.00
1.5.3	PX Instrumentation Labor	$0	5.38	$0	6.88	$0	6.88	$0	5.63	$0	24.75

III.6 Controls

Project X will have about 9 km of beam line and 1 million device properties. It will have 10x more beam power than the current NUMI beam, and it has some legacy constraints because it uses the existing Main Injector and Recycler. It should satisfy these basic requirements:

- The control system shall support machine pulse rates up to 15 Hz. Each pulse may have different characteristics and final disposition from the previous one.
- The control system shall support a scale of order 500-1000 front-end computers, 100-200 central service processes, and 200 consoles.
- The control system shall not contribute significantly to unavailability of the complex.
- The control system shall have an extensive machine protection mechanism, including hardware interlocks, software interlocks, and alarms.
- The control system shall have a fast feedback system to stabilize the beam trajectory and thereby minimize routine beam losses that can cause components to become activated.
- The control system must accommodate legacy equipment in the Main Injector and Recycler. This includes providing timing signals in the required format, and providing full control system access to those devices including archiving and alarms. Machine protection system inputs from legacy hardware shall be accepted.
- Support for subsystems developed at collaborating institutions shall be provided. It is expected this will require the control system to interoperate with EPICS based components in some manner.

A summary of the cost and effort for the Controls RD&D plan is shown in Table III-8. Detailed requirements for the controls are documented in Project X Control System Requirements document "Project X Control System Requirements" https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=2934

Controls Issues

The issues for controls include the scale, availability, safety, legacy constraints, and subsystem development outside of Fermilab.

Scale

The Project X control system will be large in comparison to most facilities, but the scale should be comparable to the current complex with the Tevatron and neutrino program.

Availability

Despite the large scale of the control system it should not contribute substantially to the overall down time of the complex. Some technical subsystems such as cryogenics will need to operate with very high availability.

Safety

Project X is targeted for 2.1 MW. At 2.1MW, an accident can cause serious damage to people and equipment. This drives the requirements of a stringent machine protection system (MPS), such as hardware and software interlocks, access control, and alarms.

With high beam power, accidents are not the only concern. Just routine losses can activate components so that they fail more often and become difficult to work on due to residual radioactivity. To prevent this, beam trajectories must be well controlled and stable. This will likely require the control system to do fast feedback.

Legacy Constraints

At the time Project X begins operation, the Accelerator Nova Upgrade will have been completed and the recycler, main injector, and NUMI beam line operated for some years in that configuration. These elements will be controlled by an evolution of the current control system. This includes field equipment, the timing system, front-end computers, services, and applications. While some changes will be needed in these accelerator components for Project X, the control system hardware and software represents a large investment that could be difficult to completely replace by the start of Project X operation. Hence the Project X control system must interoperate with or be an evolution of the existing system

Collaboration

It is expected that some subsystems for Project X will be developed outside of Fermilab by collaborating institutions. Yet they must be operated and maintained as part of the overall facility at Fermilab. As most potential collaborators use EPICS as their control system, they may prefer developing subsystems using it. The Project X control system must therefore be able to integrate EPICS IOCs and display screens. Also, as subsystems must be operated and maintained for many years after delivery to Fermilab, it is expected that standards regarding hardware and software platforms will be developed for outside development to make this long term operation efficient.

Controls Plan

The plan for controls is to evolve the current system through the Nova operations period to meet the requirements of Project X. This evolution will start with modernizing the software infrastructure to provide a reliable and modern base for future development, and provide support for EPICS interoperability. This modernization will be done first so that it is available in time for Project X RD&D (e.g., the HINS and NML efforts). The infrastructure consists of low-level systems, central services, application framework, and the software build environment. Also R&D will be done to possibly select more modern hardware platforms than the CAMAC and VME that dominate the current system. With the infrastructure specified the design of the Timing, Machine Protection and Fast Feedback systems begins. Also the specification of new higH-level applications for the Project X complex will be done.

Controls Schedule

FY09

In the first year, the work will concentrate on the requirements and design to modernize the controls infrastructure. This will include the front-end software framework and interoperability with EPICS. Evaluation of new hardware platforms will begin. Specification of a new timing protocol will also be done.

FY10

Hardware platform R&D will continue and design of the Timing and Machine Protection systems will begin. Work on the software infrastructure will expand to modernization of the software application framework.

FY11

Prototype hardware for the new Timing and Machine Protection systems will be developed. Development of the core control system infrastructure will continue. Specification of technical subsystems will begin. Standards will be developed for subsystems to be built at collaborating institutions.

FY12

Final prototypes for the Timing and Machine Protection systems will be developed, as will any prototypes required for technical subsystems. Development of the core infrastructure will continue, and software applications required for Project X specified.

Table III-8: Controls Summary

	FY09 $ and FTEs														
		FY09			FY10			FY11			FY12			Total	
		M&S	Labor		M&S	Labor		M&S	Labor		M&S	Labor		M&S	Labor
1.6	Controls	$6	0.45		$40	7.60		$140	14.85		$75	16.10		$261	39.00
1.6.1	Controls Labor	$0	0.45		$0	7.60		$0	14.85		$0	16.10		$0	39.00
1.6.2	Linac Controls M	$6	0.00		$40	0.00		$140	0.00		$75	0.00		$261	0.00
1.6.3	Transfer Line Cor	$0	0.00		$0	0.00		$0	0.00		$0	0.00		$0	0.00
1.6.4	Recycler Controls	$0	0.00		$0	0.00		$0	0.00		$0	0.00		$0	0.00
1.6.5	MI Controls M&S	$0	0.00		$0	0.00		$0	0.00		$0	0.00		$0	0.00

III.7 Cryogenics

The cryogenic system scope for Project X includes a new cryogenic plant, a cryogenic distribution system, and the necessary ancillary systems (purification system, cryogenic storage, etc.) to support the plant. The cryogenic distribution system accommodates a range of steady state and transient operating modes including RF on/RF off, cool down, and warm-up and fault scenarios. The system includes feed boxes, cryogenic transfer lines, bayonet cans, feed and end caps, string connecting and segmentation boxes, gas headers, etc. It will be capable of supporting operation of the linac within cool down and warm-up rate limits and other constraints imposed by accelerating SRF components. It will protect superconducting RF cavities from over pressurization beyond the component's maximum allowable working pressure during fault conditions. It will provide liquid nitrogen for cooling of the beam pipe in the 8 GeV transport line. The primary goal of the Cryogenic RD&D plan is to provide the systems engineering to establish a cost effective design for both construction and operation. A summary of the cost and effort is shown in Table III-9.

Cryogenics Issues

The primary issues for the cryogenics RD&D plan are the distribution and segmentation for the LE and HE linac, fault scenario protection, the balance between capital cost vs. operational cost in the design, and the understanding of the static and dynamic heat load to define the required cooling capacity.

Cryogenics Plan

The RD&D plan for Cryogenics consists of 3 elements. They are the design and optimization of the main cryogenics plant, the distribution system of 4.5K He to the LE linac, 2 K He II to HE linac, and the heat load analysis.

Cryogenics Schedule

FY09

In the first year, the work will start on all elements. Efforts include the understanding of existing cryomodule thermal cycling experience (CEBAF, SNS, FLASH), and fault scenario study.

FY10

Work on process development, the definition of tunnel distribution components and capacities, as well as definition of physical locations. Begin development of ODH mitigation strategy. Define string size limits and segments. Develop liquid helium control level strategy.

FY11

Work on definition of static and dynamic loads for all components and sub systems, optimizing technology choice for cryo plant cycle to reduce overall system capital cost vs. operational and maintenance costs. Complete interface requirements, technical specifications, and system test needs.

FY12

Complete capital vs. operational cost optimization. Investigate static and dynamic loads for all components and subsystems. Define tolerances, uncertainties and overcapacity factors for static and dynamic heat loads.

Table III-9: Cryogenics Overview

	FY09 $ and FTEs										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.7	Cryogenics	$159	1.00	$370	3.00	$96	1.00	$0	1.00	$625	6.00
1.7.1	PX Cryogenics Pl	$52	0.50	$64	2.19	$0	0.00	$0	0.00	$116	2.70
1.7.2	PX Distribution	$0	0.15	$246	0.45	$96	0.55	$0	0.00	$342	1.15
1.7.3	PX Ancillary Syst	$100	0.10	$50	0.12	$0	0.00	$0	1.00	$150	1.22
1.7.4	PX CMTB	$7	0.25	$10	0.24	$0	0.45	$0	0.00	$17	0.94

III.8 Utilities and Interlocks

Utilities to serve the accelerator components and interlocks for personnel protection will be similar to existing systems at Fermilab, and thus a minimal conceptual and preliminary design effort is needed. The cooling water system will be a conventional closed-loop Low-Conductivity Water (LCW) system. Heat will be exchanged with Industrial Cooling Water (ICW) piped from the Central Utility Building (this latter distribution is covered in the Conventional Facilities scope). This includes cooling for absorbers, which will utilize a Radioactive Water exchange loop. In addition to cooling systems, these utilities includes vacuum and various other utilities required for accelerator operations.

Assumptions

The cooling system strategy assumes that capacity is available from the Central Utility Building because the existing Linac, Booster, and Pbar systems are no longer operating. It also assumes that LCW filling and makeup water is obtained from the Main Injector LCW loop at the tie-in to the MI Tunnel.

Schedule

During the conceptual design phase, utility and interlock requirements will be developed with the subsystem leaders, and layouts for systems drawn up. During preliminary design, these plans will be refined and optimized, taking into account system commissioning requirements and construction sequencing.

III.9 Conventional Facilities

Conventional facilities include all above and below grade buildings, enclosures and utilities required to house and support the proposed Project X facility. Construction of the below-grade linac beam line and beam transport line to the Main Injector as well as the above-grade service buildings are similar to utilized and proven construction methods previously executed at Fermilab. Construction of all below-grade enclosures consists of conventional open-cut type construction techniques. The architectural style of the new buildings will reflect, and will be harmonious with, the existing buildings. The proposed site plan (See Figure 1 – Proposed Site Plan) has been optimized for the accelerator requirements. Future layouts will consider existing topography, sustainability, watersheds, vegetation, natural habitat, and wetlands and will be thoroughly addressed in the Environmental Assessment for this project.

Cost and labor effort associated with Conventional Facilities are summarized in Table III-10. Labor costs are expressed in $ rather than FTEs in this section as that is the standard costing used by the Facilities Engineering Services Section at Fermilab.

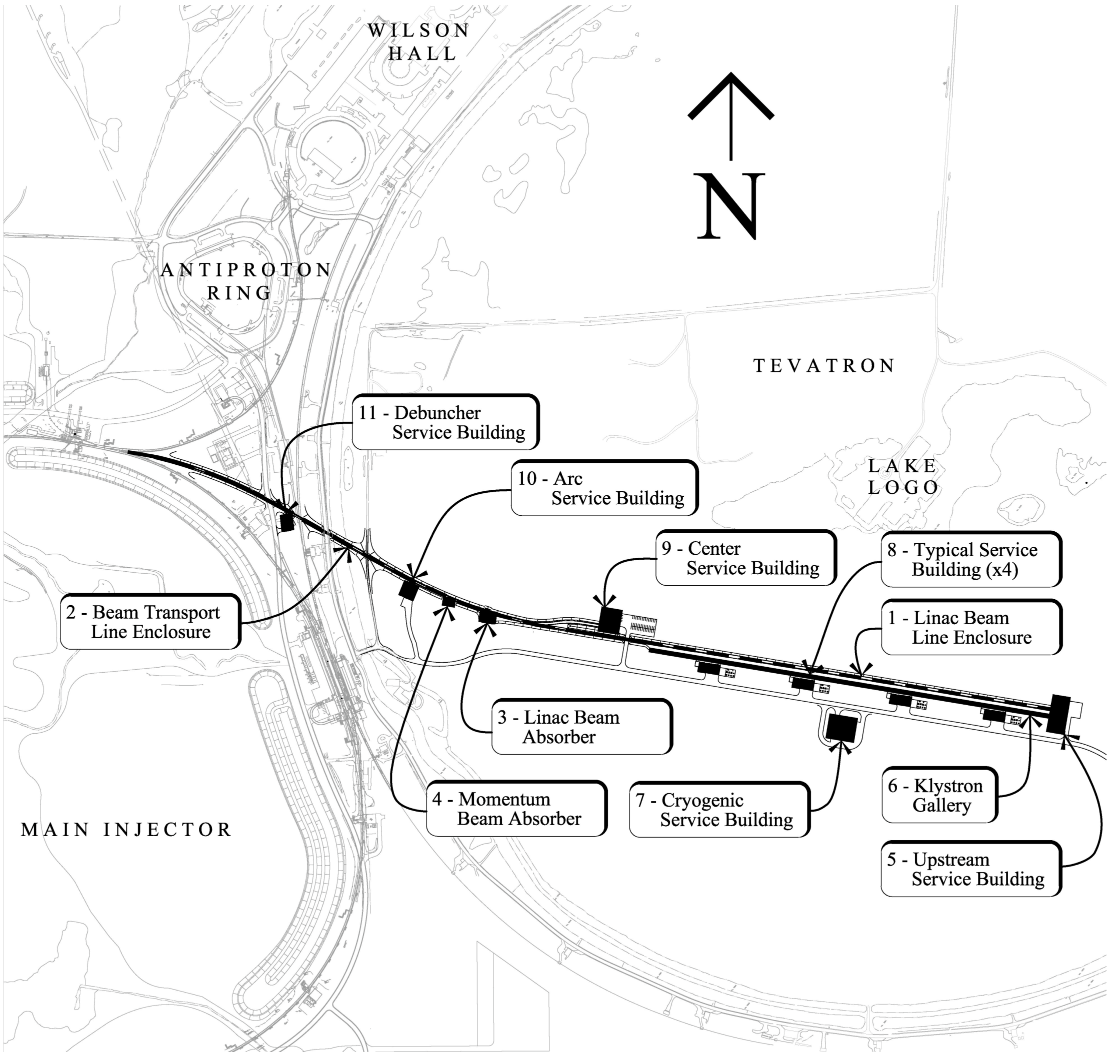

Figure 1 – Proposed Site Plan

Conventional Facilities Requirements

1. **Site work**

   The following topics address the necessary work for construction, independent of the buildings and enclosures.

   a. <u>Site Drainage</u> will be controlled by ditches and culverts while preserving the existing watershed characteristics both during construction and subsequent operation.

   b. <u>Road Construction</u> includes a new temporary construction road providing access from Butterfield Road. This road will provide direct access for construction traffic during construction only – the roadway will be restored to original condition upon completion of the project. A new service road will provide permanent access to all service buildings and utility corridor via existing lab roadways.

   c. <u>Landscaping</u> includes the restoration of disturbed areas. Construction yards and stockpile areas will be removed after completion of the construction phase of the project. All disturbed areas will be returned to a natural state or landscaped in a similar manner as found at other Fermilab experimental sites. Erosion control will be maintained during all phases of construction.

d. Wetlands Mitigation includes the avoidance or minimization of adverse impacts to wetlands in the project area. Environmental consultants will delineate wetlands, and a Clean Water Act permit application prepared for submittal to U.S. Army Corps of Engineers for impacts that cannot be completely avoided. Compensatory mitigation will be provided according to terms and conditions of the permit. This may be in the form of purchased wetland bank credits, restoration or enhancement of existing wetlands on site, or creation of new wetland areas. The permit would dictate the amount and type of mitigation, which must be in place prior to the initiation of construction. A Floodplain/Wetland Assessment pursuant to 10 CFR 1022 would be incorporated into the Environmental Assessment.
e. Space Management includes providing for a one-for-one replacement of existing for new facilities, both buildings and enclosures, on the Fermilab site. Options for space management include demolishing obsolete on-site facilities or securing replacement square footage from space banks maintained across the DOE laboratories. Some combination of these options will be used for this project.

2. Utilities

The following utilities are required to support the operation of the facility. The list incorporates current assumptions and may require further refinement as the design progresses.

a. Electrical Power includes new duct banks and utilization of existing duct banks from two sources including Kautz Road Substation (KRS) and Master Substation (MSS). Separate higH-voltage feeders with backup will be provided for conventional, machine and cryogenic power.
b. Communications include new duct banks tied into the existing communication network along Kautz Road.
c. Chilled Water (CHW & CHWR) for machine and building cooling will be supplied via new supply and return lines from the existing Central Utility Building (CUB).
d. Low Conductivity Water (LCW) for machine cooling will be supplied via new supply and make-up water from the existing Main Injector ring LCW system.
e. Industrial Cooling Water (ICW) for fire protection will be supplied via new supply and return lines from the existing D-0 Utility Corridor.
f. Domestic Water Supply (DWS) for potable water and facilities will be supplied via a new supply line from the existing D-0 Utility Corridor.
g. Sanitary Sewer (SAN) for facilities will be supplied via a new sewer main and lift station to the existing D-0 Utility Corridor.
h. Natural Gas (NGS) for building heating will be supplied via a new supply line from the existing D-0 Utility Corridor.

3. Facilities Construction

Conventional facilities will be constructed with future upgrade capabilities considered in the initial design phase. Equipment galleries, enclosures, and surface buildings will be designed to accommodate future expansion of the technical components of the facility.

Conventional Facilities Major Elements:

a. Below-Grade Construction
   Item 1 - linac Beam Line Enclosure
   Item 2 - Beam Transport Line Enclosure
   Item 3 - linac Beam Absorber

Item 4 - Momentum Beam Absorber

b. Above-Grade Construction

Item 5 - Upstream Service Building
Item 6 - Klystron Gallery
Item 7 - Cryogenic Service Building
Item 8 - Typical Service Building
Item 9 - Center Service Building
Item 10 - Arc Service Building
Item 11 - Debuncher Service Building

Conventional Facilities RD&D Activities

1. **Planning**
   a. Project Plan
      i. Contribute to Conceptual Design Report (CDR) and Technical Design Report (TDR)
      ii. Develop drawings and specifications

   b. Site Development – Master Planning of Project X facilities within existing and future experiments (μ2e, DUSEL, MI-65 Expansion, g-2, etc.) site requirements
      i. Develop Master Plan of Main Injector site area
      ii. Work across several collaborations to develop lab-wide infrastructure needs

   c. Site Characterization Studies
      i. Wetland delineation
      ii. Floodplain determination
      iii. Habitat/Archeological study
      iv. Watershed/groundwater study
      v. Soil borings

   d. Wetland Mitigation – Perform cost analysis comparison for wetland mitigation for mitigating wetlands onsite or buying credits off site
      i. Study mitigation strategies for on-site mitigation
      ii. Study mitigation strategies for buying mitigation credits off-site
      iii. Post CD-0, conduct NEPA scoping meeting with DOE, meet with Army Corps of Engineers to understand mitigation ratio requirement
      iv. Perform cost analysis

   e. Space Management (One-for-One Replacement Requirement)
      i. Study Space Management options for demolishing buildings/enclosures on the Fermilab site – determine which buildings/enclosures can be demolished and to what extent decontamination is required
      ii. Study Space Management options for purchasing credits from other DOE lab sites
      iii. Develop demolition packages, if required

   f. Environmental Assessment
      i. Begin NEPA Process - Develop NEPA execution plan
      ii. Provide input to NEPA documentation

   g. Architect/Engineer and Construction Manager Selection

    i. Determine Conceptual Design, Preliminary Design, Final Design, Independent Review timelines
    ii. Develop design resource schedules
    iii. Perform A/E selection
    iv. Perform Construction Manager selection
  h. Project Reviews
    i. Prepare and participate in CD level reviews
    ii. Prepare internal design reviews

2. Scheduling
  a. Project Schedule
    i. Develop Project Construction Schedule
  b. Construction Phasing
    i. Develop construction phasing plan, determine required construction packages, for example:
      1. Site Prep (rough grading, temp. utilities, survey monuments, piezometers, etc.)
      2. Wetland Mitigation
      3. Main Injector and MI-65 Enclosure Tie-ins
      4. Electrical Feeder Upgrade
      5. Underground Enclosures
      6. Buildings and Outfitting
      7. Cooling Pond Upgrades
    ii. Prepare preliminary design packages for each construction package
  c. Scheduling Existing Facilities (linac, Booster, Antiproton, Tevatron) remain active or in "hot spare" mode, and thus eliminate reuse of existing capabilities, such as cooling, power
    i. Work between divisions/sections/departments to determine status of existing facilities throughout the RD&D phase and beyond
    ii. Provide feedback to divisions/sections/departments regarding the needs of the project as it relates to existing facilities and infrastructure needs

3. Design
  a. Base Plan Development
    i. Perform field survey and develop base plan of existing topography
    ii. Create base map of existing utilities, roadways, structures, etc.
    iii. Create conceptual, preliminary and final design drawings and specifications
  b. Beam Layout options incorporated into preliminary/final design
    i. Complete several iterations of beam line scripts during preliminary design development
    ii. Complete cost analysis of several options including the location of injection in Main Injector and tunneling under MI-65
    iii. Finalize beam line arrangement and civil construction layouts
  c. Shielding Assessment
    i. Create Radiation Safety drawings in support of the shielding assessment
    ii. Maintain existing radiation drawings during design development

d. Alternate Configuration Document (ACD) - Support development of alternative designs into existing facilities and infrastructure
    i. Provide civil engineering in support of the ACD
    ii. Provide costing and scheduling support of alternate designs
e. Injection Abort Design - Determine if large injection abort required (significant civil construction required) or if it fit into existing tunnel near MI10
    i. Perform study of injection abort requirements (space, utilities, shielding, etc.) to determine extent of facility expansion required
    ii. Develop options for housing within existing Main Injector Enclosure or build new facility
f. Infrastructure Review
    i. Determine demand characteristics and impacts of new facility on existing infrastructure incorporating the needs of current and new experiments
    ii. Perform preliminary design for upgraded infrastructure facilities
g. Sustainability
    i. Develop LEED checklist
    ii. Incorporate "green" design principles into building design and efficiency as appropriate

Conventional Facilities RD&D Schedule

FY09

- Update existing Proton Driver design concept information with revised or additional scope with input from L2 managers (includes FESS/Eng) for CD-0 submission
- Revise cost estimate to match revised scope (includes FESS/Eng)
- Determine best approach for architect/engineer (A/E) selection process

FY10

- Begin NEPA process, including writing Environmental Assessment (involves entire project)
- Support submission of EA to DOE - involves entire project, need NEPA FONSI (Finding Of No Significant Impact) before CD-2
- Perform Site Characterization Studies
- Create Master Plan for new and future facilities
- Apply for ACOE 404 wetlands permit (must be done for EA submission)
- Further develop criteria, then design and conceptual drawings in support of CDR
- Work on Space Management Plans (needed for CD-1 approval)
- Perform architect/engineer selection to help with drafting and graphics for CDR work in this phase (and other work later on) – develop design resource schedules
- Develop work packages and construction phasing schedules
- Start developing shielding assessment documentation
- Support Alternate Design Configurations with drawing, schedules and cost ranges

FY11

- Work through iterations of EA to support achieving FONSI before CD-2

- Finalize conceptual design and drawings and text for CDR for CD-1 Review (includes FESS/Eng, A/E)
- Finalize status of existing facilities that could be reused for PX
- Contract with A/E for preliminary design work
- Perform Construction Manager selection for preconstruction services (estimating, constructability assessment)
- Develop Sustainable Design strategies

FY12

- Perform preliminary design and create drawings and text for input to Technical Design report (includes FESS/Eng, A/E, CM) for CD-2
- Perform soil borings for facilities
- Provide input into resource-loaded schedule with cost estimate and schedule information
- Develop site preparation package to final design level for expected need for CD-3 approval (FESS/Eng, A/E, CM)
- Begin advanced conceptual design for other construction packages in preparation for CD-3 (FESS/Eng, A/E, CM)

Table III-10: Construction Facilities Summary

	FY09 $										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.9	Conventional Facilities	$34	$135	$2,707	$1,575	$4,478	$1,700	$4,573	$1,620	$11,793	$5,030

III.10 8 GeV

This document discusses the Project X RD&D plan of the 8 GeV H- transport and 8 GeV H- injection into the Recycler for the configuration discussed in the ICD v1.0 document. The plan extends over the period between CD-0 and CD-2. It spans the period of FY09 to FY12. It is recognized that the ICD configuration will change which will impact the design parameters. These design changes will be reflected in the specific design parameters for absorbers, collimators, injection systems, vacuum systems, etc. It is also recognized that during the period between CD-0 and CD-1 an alternate configuration (ACD) will be investigated. This alternate design may contain multiple transport lines, rings and injection systems at different energies that will greatly impact the current RD&D plan. This plan does not explicitly contain resources for the development of an alternate configuration. Cost and labor effort associated with 8 GeV transport and injection are summarized in Table III-11.

8 GeV H- Transfer Line and Recycler 8 GeV H- injection Issues

The main issues for transport and injection of the 8 GeV H- particle beam are:

- The control and mitigation of uncontrolled losses due to single particle loss mechanisms in the transport line.
- Uncontrolled losses in the injection region due to the injected and circulating ion interaction with the stripping foil.
- The stripping efficiency and lifetime of the injection foil or the stripping efficiency of laser stripping injection system.
- The collection of the stripped electrons and neutrals from the injection process and safely disposing of them in the injection absorber.

8 GeV H- Transfer Line and Recycler Injection Plan

The Research Development & Design phase of the project is envisioned to last from CD-0 through CD-2, the transition into the Component Design, Construction, and Installation tasks. The goals for the Physics RD & Design tasks are

- To mitigate the risks associated with the four major issues discussed above
- Evaluate technology choices
- Optimize the overall system design
- Perform prototyping of components
- Perform alternative design analysis
- Perform value engineering on sub-systems as required

General Description of the Deliverables for Preliminary Design Phase

- A cost and schedule for prototyping necessary components
- Reports detailing optimization, technology choices, results of prototyping, etc.
- A defensible Conceptual Design Report in support of CD1 based upon selected design alternatives and technology choices which meet the Project X requirements. This should contain initial specifications of all the necessary components for the transport and injection system to be constructed.
- A Preliminary Design Report, based upon the conceptual design, in support of CD-2 with preliminary engineering designs for all components.

Once the preliminary design of a system is complete and the specifications for the components are given, the detailed design work under Component Design/Construction task could begin. The Component Design/Construction task could begin as early as CD-1 but many components could start as late as CD-3.

Although many of the following topics have been addressed for the Proton Driver under the High Intensity Neutrino Source (HINS) RD&D program, each topic will be revisited in conjunction with the new machine specifications and parameters for the initial configuration described in the ICD.

Description of Preliminary Design Tasks

Transfer Line RD&D

The RD&D plan for the Project X Preliminary Design of the transport line centers around the following main topics:

- Finalize a) dipole field, b) beam tube temperature, and c) beam tube vacuum specifications to mitigate uncontrolled single particle loss mechanisms of Lorentz stripping, Black Body radiation photo detachment, and electron loss due to residual gas

interaction. Perform a risk assessment on not meeting the specification and determine a tolerance for each specification.
- Finalize transfer line optics and optimize transfer line footprint to minimize civil construction impact.
- Evaluation of technology alternatives for main dipole and quadrupole magnets in the transfer line and prototype the magnets, if necessary.
- The design and prototype of a cryo beam screen and vacuum system.
- The design of transverse collimation system for large amplitude particles. This would include simulations with TRACK and design of a foil/absorber system.
- The design of a longitudinal collimation system for protection of the Recycler against errant beam energies.
- The design of a passive energy correction system (using a normal conducting superstructure) for longitudinal matching and painting into the Recycler RF injection bucket.
- The design of the linac beam dump absorber and shielding.
- Specification of instrumentation needs for the monitoring of beam positions, profiles, losses, and current.
- Detailed component specifications and preliminary engineering designs.

Recycler Injection RD&D

The RD&D plan for the Preliminary Design of the injection system is tied closely with level 4 design of the transport line and that of the Recycler RD&D in that the injection straight section must be compatible with the chicane design and the injection beam dump transport line. There are many detailed aspects that need to come together for a viable injection system. The RD&D plan for the Injection System centers around the following topics:

- The re-configuration of the current injection straight section FODO lattice into a symmetric straight section. This must be coordinated with the Recycler lattice modification.
- The design of the injection chicane. This must be coordinated with the Recycler and injection straight section lattice design.
- The choice of stripping system technology and stripping system design. There are two potential technologies that need to be developed simultaneously, foil and laser stripping. Each of these sub tasks includes not only the physics design put the conceptual design of the foil changing system or the laser configuration and the electron catcher.
- Transverse painting processes and the required magnets and power supplies.
- The longitudinal painting design. This interacts closely with the design of the warm phase rotator cavity and the low level RF system for the Recycler.
- The waste beam design that includes the transport line to the absorber and the design of the absorber and shielding.

8 GeV Transfer Line and Injection RD&D Schedule

FY09

The first year will be mainly focused on the physics design, technology alternatives, and component specification for both the transfer line and injection systems. The post CD-0 design effort will focus on the development of the conceptual design for transport and injection. Effort will concentrate on the transfer line optics and footprint and on the injection straight section design parameters, while initiating effort on the other topics spelled in section 3. This effort will be somewhat in parallel to the documentation preparation and cost preparation for the CD-0 review.

FY10

The second year will continue the effort started in the first year and will continue the evaluation of technology alternatives. An evaluation of components for prototyping will begin with a cost and schedule for the prototyping effort. It is expected that the permanent magnet dipole and quad for the beam line and a half-cell vacuum section will be likely candidates for prototyping. Effort on actual design and prototyping could begin, as time, funding, and manpower exist. Much of the effort will be toward the production of a Conceptual Design Report in support of CD1.

FY11

Prototyping of the required elements should be completed by the end of the third year and a final design for those elements underway. All to the technology choices should be resolved. Value engineering of components should occur during this time period. It is expected the effort during the third year will be focused on a technical design and specific component designs in preparation of a technical Directors Review for CD-2.

FY12

It is expected that the critical decision CD-2 will be sought during the spring or summer of the fourth year, 2012. At this stage the design should be well established with preliminary engineering designs completed and final engineering designs underway.

Multiple groups will be involved in the design of the optics of the transport line, collimation, injection layout, a transverse painting system, a longitudinal painting system, and evaluation of foil and laser stripping techniques, injection lattice design, and waste beam handling. Many of these tasks will proceed in parallel. Careful coordination between the different topics will be important. The majority of the labor during this period will consist of scientist and will include some mechanical engineering, electrical engineering, and drafting support. Regular communication between the design groups is critical and a series of design reviews should be held as needed. It is expected that at the end of the RD&D period, a consistent design based upon one of the selected injection stripping techniques will be produced with design contingencies.

Table III-11: 8 GeV Summary

	FY09 $ and FTEs														
		FY09			FY10			FY11			FY12			Total	
		M&S	Labor		M&S	Labor		M&S	Labor		M&S	Labor		M&S	Labor
1.10	8 GeV	$735	8.00		$804	7.25		$748	5.50		$593	4.63		$2,879	25.38
1.10.1	Transfer Line	$427	3.00		$496	3.13		$357	2.06		$249	1.56		$1,529	9.75
1.10.2	Recycler Injectio	$308	5.00		$308	4.13		$391	3.44		$344	3.06		$1,351	15.63

III.11 Integration

This section of the RD&D plan captures cost and effort associated with the design and development of the accelerator design (across elements) and interfaces between elements. The primary technical goal is completion of a Conceptual Design Report supported by a technology development program for CD-1, followed by a Technical Design Report demonstrating a fully developed baseline scope, cost estimate, and schedule for CD-2, for a facility with the capability of delivering in excess of 2 MW of beam power over the energy range 60 – 120 GeV, simultaneous with at least 300 kW of beam power at 8 GeV.

Major activities for the Integration RD&D program are:

- Establish requirements and design parameters for the Project X systems, establish interfaces between Project X systems
- Specify requirements and tolerances for global Project X systems and subsystems: controls, LLRF, instrumentation etc.
- Conduct Project X-specific system tests at NML test facility and at HINS test facility.
- Considers alternative designs

The Integration RD&D plan consists of the following elements:

- Physics design
- Interfaces
- System tests

Cost and labor effort associated with Integration are summarized in Table III-12.

Physics design

Lattice design

- Development of LE and HE linac lattice models
- Specifies optics interfaces
- Establishes the requirements for cryomodules and cavities

Beam dynamics modeling

- Development of preliminary beam transport model for the linacs
- Specifies tolerances for various elements (magnets, rf, aligment, stability, etc.)
- Analysis of transient behavior of the RF fields
- Study of possible static feedback and feed forward systems to cope with various beam loading and field levels in the accelerating cavities

Beam loss modeling

- Based on specified beam parameters, develop a linac beam loss model
- Specifies loss rates for shielding calculations

Static and dynamic tuning modeling

- Based on specified beam parameters, develops a preliminary model for linac tuning (e.g., at start-up, after repairs)
- Specifies beam instrumentation requirements

Failure modeling

- Determines critical Project X elements
- Determines a number of spares needed

Interfaces

Controls design

- Provides controls system requirements

LLRF design

- Models, designs and prototypes LLRF systems and its interfaces to various Project X elements.
- In addition, LLRF is also funded under "NML Test Facility Infrastructure" element of SCRF Infrastructure Plan, which contains all beam-related elements (beam inhibits, quench detection, reference line distr., LO distr, etc)

Linacs, Beam Transfer Line, Rings

- Establishes interfaces between linacs, 8-GeV beam transfer line and rings.

Conventional Facilities

- Participates in CF RD&D program by providing requirements and specifications.

Cryogenics

- Participates in Cryoenics RD&D program by providing requirements and specifications.

Machine protection design

- Develops machine protection requirements.
- Integrates it with LLRF, HLRF interlock and exception handling requirements.
- Participates in control system activities

System tests

- Essential system tests needed to be completed before or shortly after Project X construction start

RF Unit Tests

- Prepares for a high-power test of the RF unit and RF power distribution system for Project X with beam.

Controls and timing tests

- System-wide tests for near-final controls and synchronization of linac elements with the rest of Project X

Schedule

FY09

- Physics Design: Initiate work on establishing beam requirements, design parameters, lattice model, interfaces to other Project x areas and on beam loss budget.
- Interfaces: Initiate conceptual design of controls, LLRF, HLRF, civil, machine protection integration.
- System Tests: Initiate conceptual design of RF unit system test.

FY10

- Physics Design: Continue with conceptual designs, provide technical inputs and engineering requirements to technical systems. Continue beam loss modeling. Initiate modeling of static and dynamic tuning, and failure scenarios. The goal is to determine installation and alignment tolerances, power-supply regulation sensitivities, and the number of spare elements (as installed).
- Interfaces: Continue design studies, provide inputs and requirements to global (general) systems. Start design of utilities and failure mitigation systems to address the availability requirement.
- System Tests: Start procurement of long-term items

FY11

- Physics Design: Finish the conceptual design report.
- Interfaces: Prototype critical elements of the machine protection system. Finish the conceptual design report.
- System Tests: Continue work on the design for rf unit and synchronization tests.

FY12

- Physics Design: Provide support to technical areas. Provide estimates for Project cost range.
- Interfaces: Finish all prototype tests. Finish cost range studies.
- System Tests: Complete installation of rf unit test equipment, prepare to operate the test program. Install all timing and synchronization test equipment, prepare to run tests.

Table III-12: Integration Summary

	FY09 $ and FTEs										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.11	Integration	$55	9.10	$85	6.20	$175	9.00	$495	26.33	$810	50.63
1.11.1	Physics Design &	$35	3.00	$35	1.90	$46	3.00	$75	6.53	$191	14.43
1.11.2	Interfaces	$29	5.80	$64	4.00	$116	5.40	$116	6.10	$325	21.30
1.11.3	System Tests	$0	0.30	$0	0.30	$41	0.60	$383	13.70	$423	14.90