AREVA NP Inc.

Technical Data Record

Document No.: 12 - 9151202 - 001

Pebble Bed Reactor Cost and Schedule Report

BEA Contract No. 000 75310

Pebble Bed Reactor Cost and Schedule Report

Safety Related? ☐ YES ☒ NO

Does this document contain assumptions requiring verification? ☐ YES ☒ NO

Does this document contain Customer Required Format? ☐ YES ☒ NO

Signature Block

Name and Title/Discipline	Signature	P/LP, R/LR, A/A-CRF, A/A-CRI	Date	Pages/Sections Prepared/Reviewed/ Approved or Comments
Dan Grundman Engineering Manager, HTR Cost and Schedule Lead	[signature]	P	2/7/2011	All
John Mayer Advisory Engineer HTR Nuclear Island	[signature]	R	2/7/2011	All
Lew Lommers HTR Project Engineering Manager	[signature]	A	~~2/7/2011~~ 2/8/2011	All
Farshid Shahrokhi HTR Technical Integration Manager	[signature]	A	~~2/7/2011~~ 2/8/2011	All

Note: P/LP designates Preparer (P), Lead Preparer (LP)
R/LR designates Reviewer (R), Lead Reviewer (LR)
A/A-CRF designates Approver (A), Approver of Customer Requested Format (A-CRF)
A/A-CRI designates Approver (A), Approver - Confirming Reviewer Independence (A-CRI)

Record of Revision

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description/Change Authorization
000	All	Initial issue
001	All	Re-issued to incorporate customer requested clarifications to various sections. • Revised fuel cost sections for demonstration plant and commercial plant • Revised licensing section for PBR demonstration plant and revised Table 4-10. • Removed R&D costs and clarified references to R&D and technology development costs. • Correction of units on Figure 4-4. Updated total plant costs incorporating correction to input data

List of Contributors

AREVA NP Inc.
Dan Grundman
Mike Gould
Farshid Shahrokhi
Lew Lommers
John Mayer

AREVA GmbH
Herr Dr. Gerd Brinkmann
Dieter Vanvor

AREVA SAS
Jean-Claude Lefevre

The Shaw Group, Inc.
Peter Wells
Ryan Hannink
Reiner Kuhr
Robert Wilmer
Paul Slatkavitz
Tom Vivenzio
Jeff Ashworth
Richard Berry
Elizabeth Westergren

Table of Contents

Table of Contents
(continued)

Page

List of Tables

List of Tables
(continued)

Note: Gaps in table number sequencing are due to deletions during review or revision. To maintain consistency between revisions, tables have not been re-numbered.

List of Figures

Note: Gaps in figure number sequencing are due to deletions during review or revision. To maintain consistency between revisions, figures have not been re-numbered.

1.0 INTRODUCTION

This report provides cost and schedule estimates for Pebble Bed Reactor (PBR) nuclear power process heat applications as a "first of a kind" (FOAK) Demonstration Plant and as an "n^{th} of a kind" (NOAK) multi-module Commercial Plant assumed to be part of a fleet of PBR plants. The project cost and schedule for the PBR Demonstration Plant cover design, licensing, fabrication, construction, and initial operation

1.1 NGNP Project

The high temperature gas-cooled reactor (HTGR) can provide an important addition to the U.S. and the world's energy supply portfolio. Enabling commercial deployment of the HTGR technology has gained importance as environmental and energy security issues have become more apparent, and the national resolve to solve these issues has become stronger. The Next Generation Nuclear Plant (NGNP) Project authorized by the Energy Policy Act of 2005 (EPAct) provides for a collaborative effort between government and industry to enable the commercialization of the HTGR technology.

To achieve this goal, the NGNP Project must develop and demonstrate the design, licensing, performance, operational capabilities, and economic viability of HTGR and associated process heat technologies. The Project must further enable development of the commercial vendor/owner/user infrastructure, and support the timely Design Certification of the commercial designs by the NRC to help assure subsequent deployment in the commercial market place.

Currently, the NGNP Project is a Government-sponsored project focused on the development, early design and licensing of an advanced HTGR and the associated advanced technologies to transport the high temperature process heat. The basis for the HTGR technology embodied in the NGNP was first developed over 40 years ago in the UK, the U.S. and Germany. Most of the previous work has focused on the generation of electricity. Seven experimental and demonstration reactors have been built world-wide, including a U.S.A. commercial scale demonstration of a specific HTGR concept for electric power generation at the Fort St. Vrain plant that operated from 1976 through 1989. Other HTGR system-related development efforts exist in South Africa, France, Japan, Russia, and China at the design stage or engineering pilot scale. Additionally, a commercial scale demonstration plant utilizing the pebble technology is currently under construction in China.

As currently envisioned, the NGNP Project will result in full scale First-of–a-Kind (FOAK) facilities that demonstrate the commercial potential of the HTGR and associated technologies. Definition of the specific NGNP facilities to be built as part of the Project will be established over the next several years. The conceptual design for two HTGR technologies are being developed as part of the initial phase of the NGNP project. The prismatic design concept is being developed under a DOE FOA funding by the General Atomics design team and the pebble bed HTGR reactor technology concept is being evaluated by the AREVA design team. As the conceptual design and technology assessment work progresses, the facility design is better defined, and the costs and the economics of the project are defined with more certainty.

1.2 NGNP Project Objectives

The primary goal of the NGNP Project is enabling the commercialization of the HTGR technology across new industrial and commercial markets previously not accessible to nuclear technology. The NGNP Project will create the option for deployment of the HTGR technologies for a range of applications and sites not traditionally served by nuclear energy.

Key objectives for achieving this goal include:

- Fully characterizing the potential market through end-user collaborations and application studies in order to identify a wide range of viable candidate sites, applications and projects

- Providing guidance to design teams regarding the range of site and application requirements that could impact NGNP design and licensing
- Preparing, submitting, and acquiring one or multiple Early Site Permits (ESPs) that envelop the range of potential sites and applications for deployment of HTGRs
- Performing the design activities necessary to prepare, submit, and eventually obtain a Combined License (COL) for one or both HTGR technologies
- Developing the regulatory framework for the licensing of the HTGR technologies
- Enabling the long-lead developmental activities for fuel, high-temperature materials, and methods that support licensing and subsequent construction of the FOAK facilities
- Securing the fuel fabrication capacity needed to support HTGR projects
- Completing the final design activities to allow construction, start-up, confirmatory testing, and operation of the FOAK facilities
- Acquiring the necessary government incentives to make the FOAK facilities economically viable investments for the private sector
- Construction, start-up, confirmatory testing, and completing a commercial operations run for the FOAK facilities
- Enabling the establishment of the supply chain infrastructure necessary for commercial build-out of the HTGR technologies
- Obtaining design certifications from the NRC to support the deployment of the initial fleet of commercial plants
- Capturing the lessons learned from FOAK construction and operations, and validating the assumptions for future plant construction costs and schedule

By meeting the objectives above, it is expected that the NGNP Project will establish an acceptable basis for commercial deployment of the HTGR technology in the broader energy sector. Completing the design, licensing, construction and initial operations of a FOAK plant provides a solid foundation for commercialization and commitment to the extensive deployment anticipated for the HTGR technology, end-user site requirements and hazards, and nuclear-industrial collocation conditions.

1.3 PBR Technology Status Assessment

The U.S. Department of Energy (DOE) has selected Idaho National Laboratory (INL) as the lead national laboratory for nuclear energy research. Per the terms of the EPAct, Title VI, Subtitle C, Section 662, INL, under the direction of DOE, will lead the development of the NGNP by integrating, conducting, and coordinating all necessary research and development activities, and by organizing all project participants, including industry. INL will also be responsible for conducting site and project related procurements, and coordinating project efforts within the industrial and international communities.

As required by the EPAct, the Nuclear Energy Advisory Committee (NEAC) will conduct a “first project phase review,” when the first phase of NGNP is nearly complete. The first phase of NGNP includes the research and development, technology, licensing, and conceptual design information derived from all Phase 1 activities. Two main technology options are under consideration for the NGNP: the prismatic block core modular HTGR, and the pebble bed reactor (PBR) modular HTGR. The evaluation of these two reactor concepts will form an important part of the Phase 1 review. Conceptual design information for the prismatic reactor concept is being developed under a separate work scope. The purpose of this work is to develop key information to support the review of the PBR technology option.

This effort will provide a limited assessment of the PBR concept that includes the basic design information and various assessments of the design concept needed to evaluate the maturity of the PBR design concept and its technical readiness to advance to the next level. This work did not intend to produce a conceptual design of the NGNP reactor with the PBR technology.

The bases for the PBR technology readiness status assessment is the AREVA HTR-Module design developed in Germany in the late 1980s plus enhancements that support current requirements, safety, and licensing. Adjustments to the referenced plant design would be considered based on HTGR design experience since the HTR-Module was not originally developed to meet the NGNP requirements. The pertinent NGNP requirements are reactor outlet temperature of 750°C or greater, electricity production, and heat for other process applications.

An evaluation of the readiness of this design is made using trade studies and expert engineering judgments. The results of these assessments are documented in four deliverables:

1) The Plant Design Description report – PDD describes the reference PBR design that is based on the HTR-Module and identifies potential design enhancements. The PDD identifies key system requirements, describes the overall PBR plant and provides a description of each critical structure, system, and component (SSC). Engineering analyses and trade studies, such as a point design and steady-state plant analyses, shall be performed to adapt the previous designs to the NGNP requirements.

2) The PBR Technology Readiness Assessment report – The technology readiness assessment comments on the readiness status of various technologies necessary to build the NGNP with PBR technology. An existing set of design data needs (DDN) will also be reviewed and potential changes or modifications will be recommended. A study evaluating the overall PBR technology readiness for deployment was performed. This study performed the following: a) examined key PBR technology issues, b) identified technology needs by evaluating the existing design data needs (DDNs) for the PBR design and gaps in the identified needs, c) discussed fuel and graphite qualification and acquisition, and d) discussed the constructability and component transportability of the PBR design concept.

3) The PBR Scoping Safety Study report– In the safety study report the PBR safety case is presented and discussed, the original German HTR-Module accident analysis results are provided and discussion of key technical issues relevant to PBR safety case is presented. The scoping safety study is based on existing analyses; new analyses are not within the scope of this work. This work included review of prior HTR-Module safety analyses. The review included identification and assessment of the PBR plant safety issues and discussion/assessment of the expected outcomes for each major accident sequence. Considerations specific to the PBR technology, such as graphite dust and the requirement for a stochastic approach to the core design and analysis, are reviewed and discussed. The safety study also includes an evaluation and discussion of expected dose at the site boundary (about 400m) for accidents with dose releases using accepted U.S. dose calculation methodology and with the original accident source terms.

4) The Cost and Schedule report (this report) – This report provides an updated cost and schedule for the PBR FOAK and the NOAK plants. Cost and schedule estimates for deployment of the PBR are developed for the FOAK and NOAK plants. The cost estimate is based on historical information from previous PBR evaluations and similar components as appropriate with scaling, and adjusted as necessary to match the current PBR design concept. The cost estimate addresses a single plant for the FOAK plant and a multiple plant installation for the NOAK. The plan includes an overall project schedule covering detailed design, fabrication, and construction of the demonstration PBR plant.

1.4 Purpose of Cost and Schedule Estimate

The cost estimates and schedule presented in this report are intended to support the evaluation of PBR technology by providing an overview of the economics and timeframe required to construct and operate a FOAK PBR based on existing technology and for mature commercial NOAK projects using this technology. The cost estimates are indicative (±40%). This overview can be used by the NGNP project for decision making and strategic planning for future NGNP initiatives. An economic comparison of the Commercial Plant versus a conventional combustion turbine cogeneration unit provides a basis for understanding market competitiveness when this technology is fully commercialized as gas prices rise and CO_2 production is penalized.

1.5 Document Structure

This report is organized into two sections. The first presents the cost estimates and cash flows for the PBR Demonstration Plant and cost estimates for the PBR Commercial Plant. The second presents the schedule for the PBR Demonstration Plant. Risk items associated with both cost and schedule are included in Section 7.0.

The PBR Design Description Report provides a comprehensive description of the design of the PBR, which provides a basis for the work in this report.

1.6 Terms, Abbreviations, and Acronyms

A list of terms, abbreviations, and acronyms used in this Pebble Bed Reactor Cost and Schedule Report are included in Table 1-1.

Table 1-1: List of Terms, Abbreviations, and Acronyms

BEA	Battelle Energy Alliance
BOP	Site and Balance of Plant
CO_2	Carbon Dioxide
COL	Combined Construction and Operating License (NRC)
DOE	United States Department of Energy
ECP	Energy Conversion Plant
EPC	Engineering, procurement, and construction
ESP	Early Site Permit
FOAK	First of a kind
HP Steam	High Pressure Steam
HRSG	Heat Recovery Steam Generator
HTGR	High temperature gas-cooled reactor
HV	High Voltage
HVAC	Heating, Ventilation, and Air Conditioning
I&C	Instrumentation and Controls
INL	Idaho National Laboratory
ISFSI	Independent Spent Fuel Storage Installation
ITAAC	NRC requirement for confirming completion of construction and startup consistent with approved COL requirements
LP Steam	Low Pressure Steam
LWA	Limited Work Authorization
LWR	Light Water Reactor
NGNP	Next Generation Nuclear Plant (DOE/INL program to commercialize HTGRs)
NOAK	n^{th} of a kind
NRC	United States Nuclear Regulatory Commission
NSS	Nuclear Steam Supply Facility
O&M	Operations and Maintenance
PBR	Pebble Bed Reactor
PBR Commercial Plant	A future installation of multiple PBRs assuming a mature design and supply chain
PBR Demonstration Plant	The first U.S. installation using the PBR
PBR Design Description Report	Comprehensive description of the design of the PBR Demonstration Plant and the PBR Commercial Plant
PPP	Public Private Partnership
R&D	Research and Development
RPV	Reactor Pressure Vessel
TG	Turbine Generator
USGC	United States Gulf Coast

2.0 SUMMARY AND CONCLUSIONS

The major results presented in this report include capital cost estimates, indicative cash flows, and implementation schedules for the PBR Demonstration Plant and the PBR Commercial Plant. The cost estimates are indicative, which is ±40%. Risk items and opportunities for cost reduction are also presented in this report.

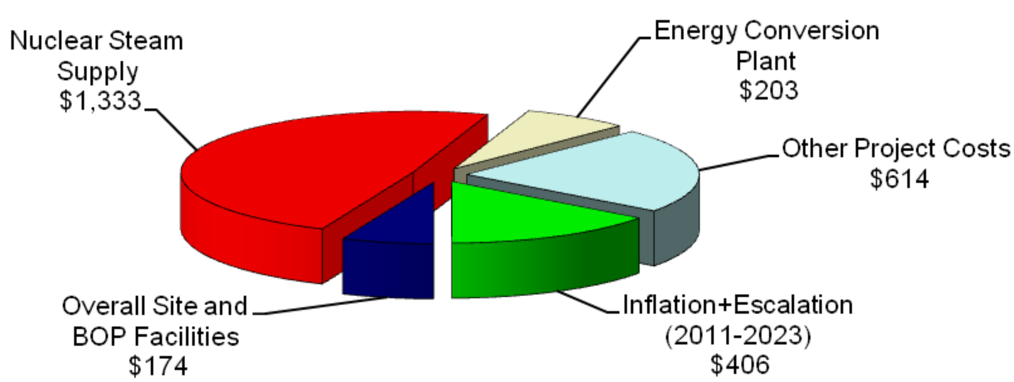
2.1 PBR Demonstration Plant

The PBR Demonstration Plant is an HTR-Module which consists of two PBR reactors and steam generators coupled to a steam turbine generator with extraction ports designed to provide steam to an adjacent process facility through reboilers. The function of this design in terms of steam supply is equivalent to a conventional design using a combustion turbine with a heat recovery steam generator (HRSG) to provide process steam.

2.1.1 Capital Cost

The capital cost estimate was developed by adapting cost estimates prepared in Germany in 1991 for the nuclear steam supply system facility (NSS), and by factoring balance of plant (BOP) areas from other projects based on capacity and other parameters. Figure 2-1 shows the capital cost breakdown.

Figure 2-1: PBR Demonstration Plant Capital Cost Summary



Total Cost $2,730M (Costs are in $M)

This capital cost estimate is considered to be indicative (±40%), given a number of assumptions regarding site and project conditions and interfaces, which can vary widely for actual projects. NSS costs were derived using high level factoring from escalated original German estimates without the benefit of detailed definition or quantities to support a full understanding of the source estimates. Energy Conversion Plant (ECP), BOP costs, and Other Project Costs were factored from other estimates and projects based on a number of assumptions. Other Project Costs include conceptual and preliminary engineering, nuclear licensing, project development and financing, and owner’s costs related to project management, commissioning and startup, first fuel, and initial operations. Many of these costs are considered FOAK and would be reduced or eliminated for subsequent projects as elements of the project become commercially available. These costs have been adjusted in the NOAK commercial plant estimates.

2.1.2 Demonstration Plant Development Schedule

The overall schedule duration for this FOAK Pebble Bed Reactor is 12 years. This schedule is primarily driven by the following key activities:

- Design Criteria Reconciliation and Preliminary Design
- Preparation of Construction and Operating License (COL) application
- NRC review of the COL Application
- Fabrication and Delivery of Long Lead Equipment
- Completion of Early Site Work
- Construction, Commissioning, and Startup of the NSS, ECP and BOP

The design criteria reconciliation and preliminary design activity takes advantage of the existing advanced conceptual design and the extensive work preceding this effort. It is important that site selection and plant down-select be finalized at least 6 months prior to the completion of preliminary design to support engineering of the ECP and BOP.

The Combined Operating License Application (COLA) preparation is a 2 year activity, completing 6 months after completion of the preliminary design. Prior to initiating the COLA, a Regulatory Management Plan will be developed with input from the NRC to detail the scope and content of the application. The COLA will draw on PBR design criteria adapted for the U.S., the safety analysis and the numerous studies completed during the early phases of this project to satisfy the application content requirements.

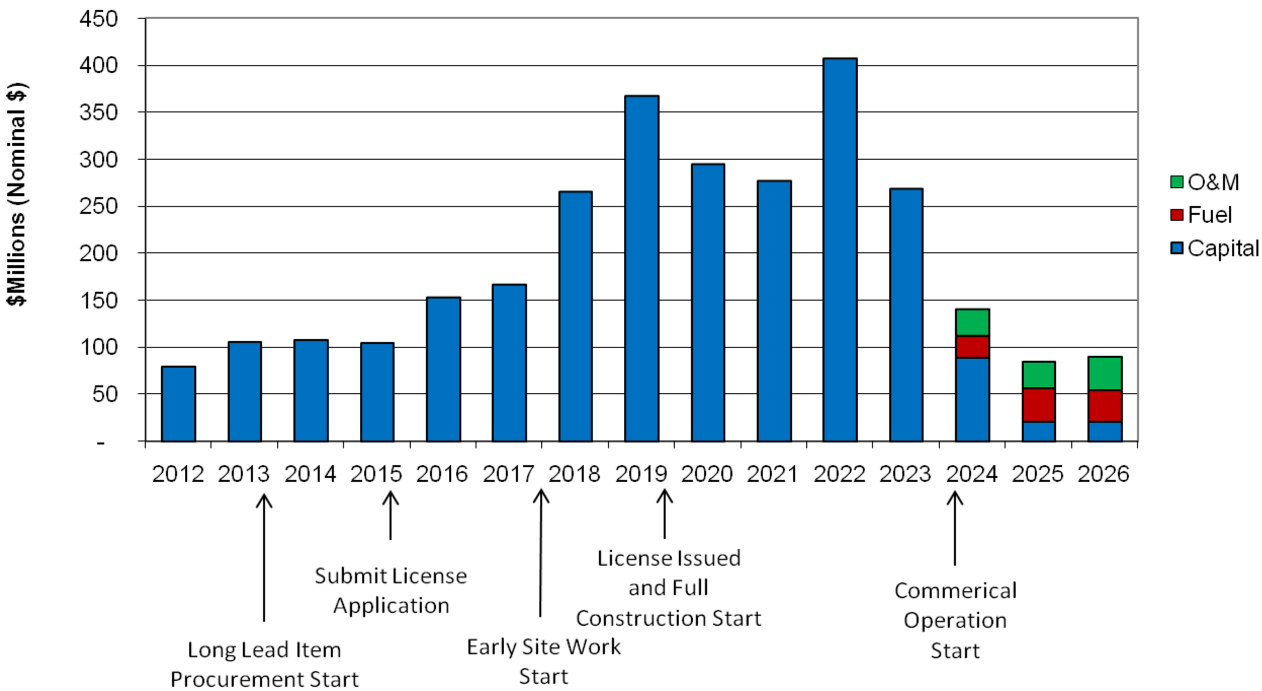
The schedule requires an early submission of the license application, 6 months after completion of preliminary design. Four years have been allowed for the NRC review, recognizing that potential gaps exist in the existing regulations for this FOAK plant, which will likely impact the review process. It is expected that the NOAK plants will experience a much more streamlined licensing process. The COL approval is required to start construction, which is also on the critical path for this project.

The construction schedule is highly dependent on the completion of significant early site work activities and the characteristics of the site selected for the plant. This site work includes grading, excavation, underground utilities, batch plants, heavy lift cranes, construction facilities, delivery of reinforcing steel and embedded material for the first 6 months of construction, initial construction contracts awarded and qualified contractors mobilized. All pre-requisites must be completed to allow construction to start as soon the COL is received. Long lead equipment will be scheduled for delivery so that it is ready for installation at least six months prior to construction installation. The procurement of long lead equipment will require a significant financial commitment long before the start of construction. This funding requirement is discussed in the discussion of costs and cash flow below. The plant design will maximize modular construction and assembly testing prior to installation to optimize field construction activities.

2.1.3 Cash Flow

Cash flow for the period from Conceptual Design through the full operation is summarized in Figure 2-2.

Figure 2-2: PBR Demonstration Plant Cost Cash Flow



Note the extensive engineering costs to support nuclear licensing prior to the beginning of construction in 2019.

2.1.4 Conclusions and Recommendations

Based on the work completed to develop indicative cost estimates and cash flows for a PBR Demonstration Plant, the following related conclusions/recommendations are provided:

1. The indicative capital cost estimate for the PBR Demonstration Plant is expected to have an accuracy of ±40%.
2. Design reconciliation of the conceptual design is needed to develop design information including equipment lists, flow diagrams, arrangement drawings, and construction quantities, which are needed to support a more definitive estimate.
3. The context of an actual site and specific application is needed to define interfaces, and operating requirements, which could have considerable impact on plant costs and cash flow.
4. Final resolution of nuclear safety requirements through COL licensing can also impact design and cost.

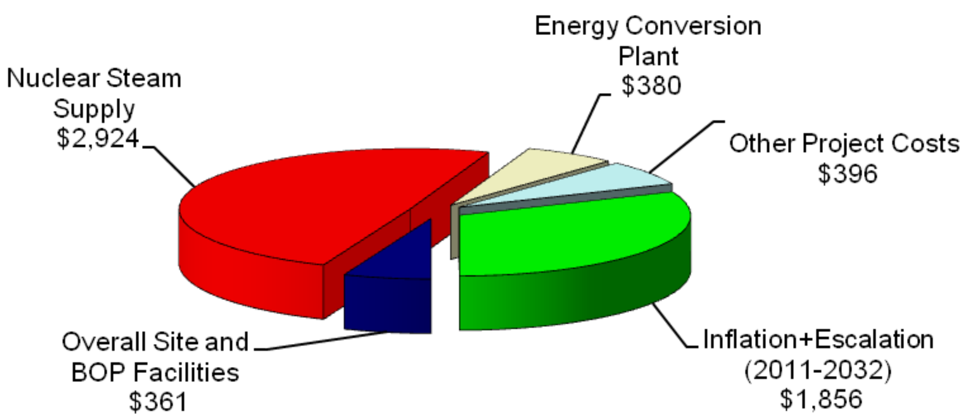
2.2 PBR Commercial Plant

The PBR Commercial Plant consists of eight PBR reactors each with its own steam generator (4 HTR-Modules) providing steam to two steam turbine generators, with extraction ports designed to provide steam to an adjacent process facility coupled through reboilers. The function of this design in terms of steam supply is equivalent to a conventional cogeneration design using combustion turbines with heat recovery steam generators to provide process steam. Steam turbine generators would be optimized for each specific application to utilize some of the steam for power generation and provide extraction or exit steam to the host site. In some cases the steam turbine generator becomes a small topping turbine or can be eliminated if the economic emphasis is on steam generation and where high energy steam is used elsewhere in the host facility to drive turbines for mechanical drives and power generation.

2.2.1 Capital Cost

The capital cost estimate was developed by adapting cost estimates prepared in Germany for the nuclear steam supply system, and by factoring balance of plant areas from other projects based on capacity and other parameters. FOAK costs from the Demonstration Plant were removed, and savings due to learning and sharing were deducted based on reasonable assumptions. A capital cost summary for an eight reactor commercial facility is shown in Figure 2-3.

Figure 2-3: PBR Commercial Plant Capital Cost Summary



Total Cost $5,918M (Costs are in $M)

This capital cost estimate is considered indicative only (±40%), given a number of assumptions regarding site and project conditions and interfaces, which can vary widely for actual projects. Commercial projects designed to provide process steam can vary widely in design and performance based on specific project requirements and site characteristics. Nuclear steam supply system costs were derived using high level factoring from original German estimates without the benefit of detailed definition or quantities to support the source estimates. Energy conversion and BOP costs were factored from other estimates and projects based on a number of assumptions. The design includes space for a full steam turbine generator and auxiliaries, which could be minimized or eliminated for some applications. Other Project Costs include allowances for limited preliminary engineering, nuclear licensing, project development and financing, and owner's costs related to project management, commissioning and startup, first fuel, and initial operations considering the effect of experience from several projects following the Demonstration Plant.

2.2.2 Lifecycle Economic Evaluation

Process heat applications for the PBR Commercial Plant can vary widely in terms of how steam from the NSSS is utilized to produce electricity and process steam. This means that the ECP design can range from using large steam turbine generators with small amounts of steam extraction feeding small reboilers, to a very small topping steam turbine generator, or no steam turbine at all for cases where the host site demands high pressure steam for utilization in its existing steam turbines for driving mechanical equipment and generators. If most of the steam is utilized to produce electricity, the economic analysis tends to resemble that of a power generation unit competing with power available from the grid or onsite power generation. As the use of steam shifts from power to process steam export, the cost of steam turbine and related equipment is reduced while the cost of reboilers and high energy pipe increases. Although the equipment costs may change from application to application, the total costs of the ECP and BOP are expected to not to change dramatically and are a relatively small portion of the total capital relative to the NSSS.

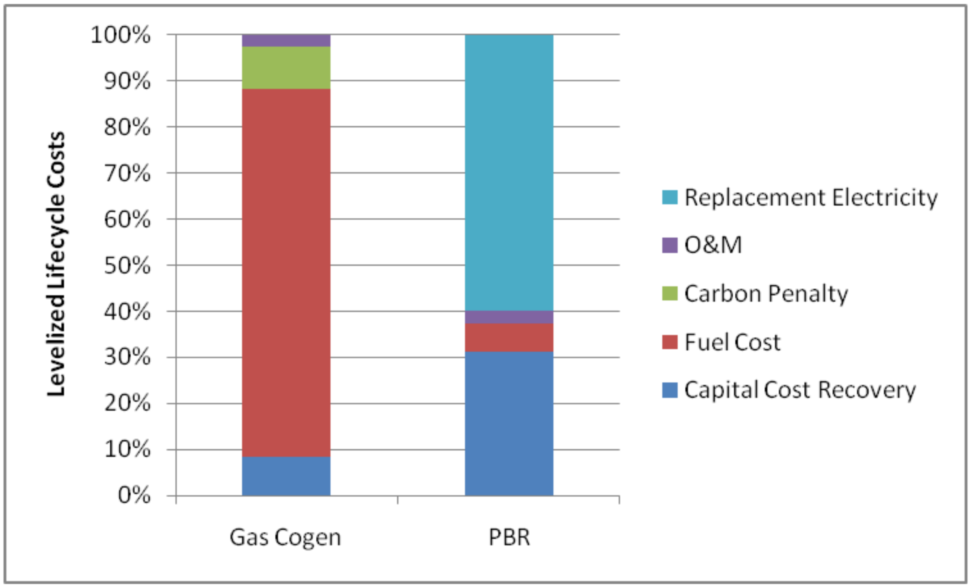
Most large industrial, chemical and petrochemical facilities that constitute the potential market for large onsite cogeneration applications have existing integrated steam systems using high, intermediate and low pressure steam currently supplied by process heat recovery boilers and combustion turbines with heat recovery boilers. As a host to a PBR Commercial Plant, they are likely to define an interface based primarily on steam output with power generation considered secondary in the design of a plant. Industrial combustion turbine cogeneration units are designed and dispatched to provide reliable steam supply for large process production units and operate in coordination with other steam supply sources based on heat recovery from various process units. Power production from the combustion turbines is used or sold as necessary, but normally considered as a secondary factor in design or dispatch.

In order to represent a true process heat application, the PBR Commercial Plant is adapted to produce high energy steam for the host facility with no electrical power generation. This provides a representative case which brackets the range of application conditions. The other extreme, producing only electrical power, is not considered a process heat application and is not developed for this study.

Lifecycle economics are modeled for the PBR Commercial Plant versus a gas fired cogeneration unit producing the same amount of steam from heat recovery steam generators. Results of this comparison suggest the PBR Commercial Plant generally provides steam at costs comparable to what can be provided with a conventional combustion turbine cogeneration unit burning natural gas in the $10-12/MMBtu range. These results are sensitive to a number of assumptions, and consider that the combustion turbines produce a large amount of electric power in addition to providing process steam. It is expected that optimizing the PBR Commercial Plant application design based on site specific conditions will result in lower breakeven gas costs by providing the best combination of steam and power. Since no specific site or application basis was provided for this analysis, this economic comparison is considered a “worst case” scenario.

Figure 2-4 presents a comparison of the components that make up the lifecycle costs of nuclear and conventional steam supply plants, assuming a 40 year life, with gas price set at the breakeven point of $10.56/MMBtu and a carbon penalty of $25/tonne CO_2. The figure shows that capital recovery is the dominant component of the PBR plant lifecycle cost while fuel is the dominant component of the gas cogeneration plant lifecycle cost. Replacement electricity is used to equate the outputs of the two plants and is large for PBR because of the large amount of export electricity the gas cogeneration plant produces along with the steam.

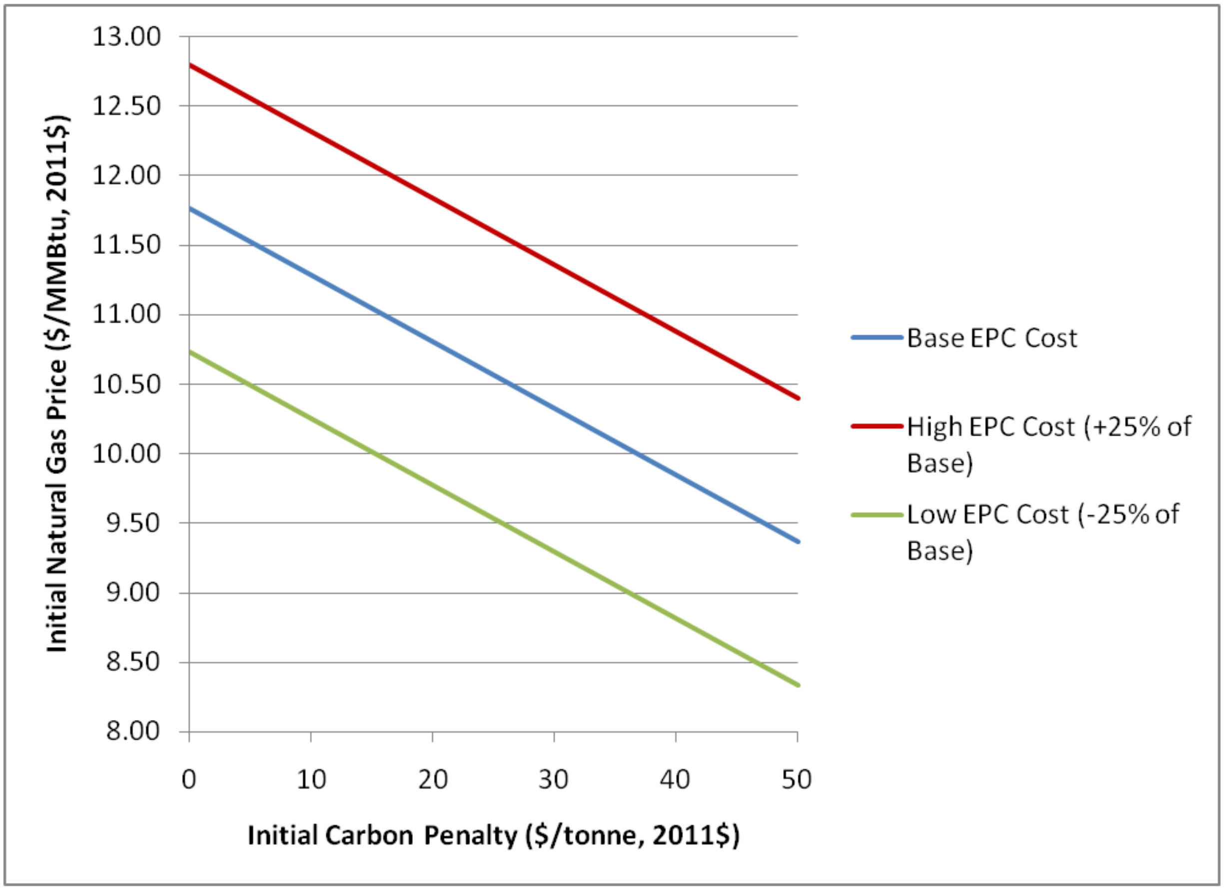
Figure 2-4: Lifecycle Cost Comparison of PBR Commercial Plant versus Gas Fired Cogeneration Plant



Because of the high level of uncertainty that surrounds both future natural gas prices and future carbon penalties, these parameters were varied to understand these relationships. The breakeven natural gas price is the initial natural gas price (at the start of commercial operation in 2032 in 2011 dollars) that results in the PBR Commercial Plant and the natural gas fired cogeneration plant having the same lifecycle economic value (the same net present value of costs and revenues over the lives of the projects). 2011 dollars without inflation are used in this analysis to better visualize the magnitude of these economics relative to current conditions. Utilizing the assumptions of this approach, when natural gas prices rise above the breakeven price then the PBR Commercial Plant is more economical than the gas cogeneration plant; therefore, the economics of the PBR improve with decreasing breakeven natural gas price. Sensitivities of gas breakeven cost to PBR capital cost and carbon penalty are illustrated in Figure 2-5. As the carbon penalty increases, the breakeven natural gas price decreases. Without a carbon penalty the breakeven natural gas price is $11.76/MMBtu and with a carbon penalty of $50/tonne CO_2 the breakeven natural gas price decreases to $9.36/MMBtu. A 25% change in PBR capital cost shifts the breakeven natural gas price by ~$1/MMBtu. With a $50/tonne CO_2 penalty and 25% lower EPC costs, the breakeven natural gas price would be just over $8/MMBtu. During the last five years in the United States natural gas prices peaked at $15/MMBtu and were sustained above $8/MMBtu for months at a time; however, current prices are around $4.50/MMBtu and will have to increase significantly in real terms between now and the start of commercial operation and continue to increase during the plant lifetime for the PBR to be more economical than the gas cogeneration plant alternative.

The value of the large amount of power produced by the gas fired combustion turbines significantly influences the breakeven natural gas price. As the cost of power available from the grid increases, the PBR case requires a higher gas price to breakeven with combustion turbine cogeneration.

Figure 2-5: Sensitivity of Breakeven Gas Price to Capital Costs and Carbon Penalty



3.0 PEBBLE BED REACTOR PLANT PROJECT DESCRIPTION

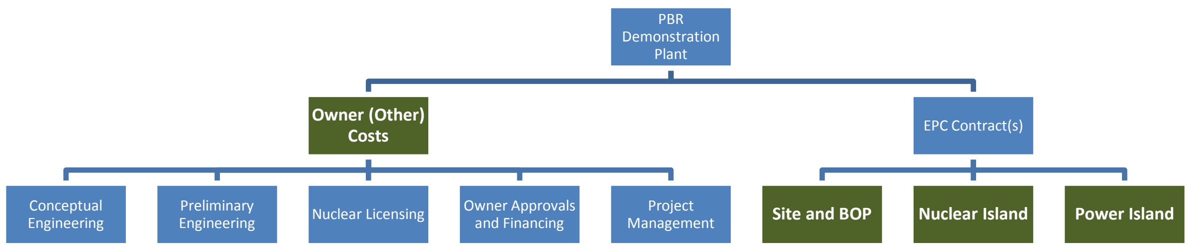
The PBR Demonstration Plant and the PBR Commercial Plant are based on the same reactor design, but are different in the number of two reactor HTR-Modules and balance of plant design to reflect the benefits of sharing, learning, and completion of FOAK costs.

The NSS designs of the PBR Demonstration and Commercial Plants are based on the HTR-Module. Detailed descriptions and drawings of the HTR-Module conceptual design are provided in the PBR Design Description Report. Summary descriptions of each are provided below to establish a basis for cost and schedule development.

3.1 PBR Demonstration Plant

The PBR Demonstration Plant project is organized into four major cost accounts for purposes of estimating development as shown in figure 3-1.

Figure 3-1: PBR Demonstration Plant Work Breakdown



3.1.1 Owner (Other) Costs

Much of the Owner's cost for the PBR Demonstration Plant includes FOAK engineering and nuclear licensing that, once completed, should not re-occur or would be substantially reduced for subsequent projects. Non-recurring FOAK scope for the PBR Demonstration Plant is included in the following major efforts:

- Conceptual design criteria reconciliation to U.S. requirements for a specific site and application to provide definitive scoping, budget pricing, and implementation planning
- Preliminary engineering to support licensing and to develop complete design documentation, establish major supplier and EPC agreements, and prepare comprehensive implementation plans, budgets, and schedules
- Obtaining a COL from the NRC
- Securing owner's regulatory and stockholder approvals and structuring financing, including substantial stakeholder and government support for FOAK items
- Establishing an owner's management team and management systems to oversee project budgets, schedules, contracts, quality, and implementation of regulatory requirements

Other non-EPC work undertaken by the Owner prior to obtaining a COL and construction financing is described in the following sections.

3.1.1.1 Conceptual Design

A 9 month period for a design criteria reconciliation effort will be required to:

- Document specific (U.S.) site and application requirements;
- Establish a project specific basis of design;
- Engage with NRC to define pre-licensing requirements and activities;
- Develop a formal safety case to prepare for nuclear licensing and to determine related design requirements;
- Adapt previous design work for U.S. codes, standards, and practices;
- Prepare definitive technical descriptions, drawings, and diagrams to support conceptual estimate development;
- Define major equipment and systems sufficiently to obtain major supplier budget quotations and design information to support BOP design;
- Develop preliminary equipment lists, material take offs to establish indicative construction quantities and bill of materials;
- Develop a provisional project implementation plan to define indicative budgets, schedules, commercial arrangements, and plans for project management, owner approvals and financing, vendor related

product development, engineering and design, procurement, nuclear licensing, quality, construction, nuclear fuel supply, commissioning and startup, and commercial operations; and
- Prepare a Conceptual Project Cost Estimate based on budget pricing for major equipment and indicative pricing for the remainder of the plant based on conceptual design information, as well as establish project budgets by including allowances for uncertainty and contingencies based on initial risk analysis.

The conceptual design effort for the PBR Demonstration Plant represents a major FOAK effort. The cost of this effort is expected to be supported by technology and application stakeholders, including the U.S. government.

The basis for conceptual engineering costs prepared for this estimate assumes an average labor cost of $125 per hour and includes the following:

- Engineering effort
- Nuclear pre-licensing effort
- Project planning and management

These budgets are indicative only and can vary substantially once specific project requirements are established. An overall budget of about $25.2 M is included in Table 4-7.

3.1.1.2 Preliminary Design

A preliminary design effort will be required to:

- Formalize site and application requirements into Owner/off taker agreements;
- Formalize a project specific basis of design into supply and EPC agreements;
- Finalize safety case to support detailed design requirements;
- Prepare specifications for procurement packages;
- Prepare definitive technical descriptions, drawings, and diagrams to support procurement and construction planning based on provisional vendor inputs;
- Define major equipment and systems sufficiently to obtain major supplier firm bids and design information to support preliminary BOP design;
- Develop equipment lists, material take offs to establish preliminary construction quantities and bill of materials;
- Finalize and begin implementation of project plans to fix budgets, schedules, contracting and procurements, and project management to support owner approvals and financing;
- Implement plans for technology/vendor development;
- Implement plans for engineering and design configuration management and quality control;
- Secure nuclear fuel supply for completion and early commercial operations;
- Finalize planning for commissioning and startup, and ITAAC compliance;
- Complete major Project Agreements, including Host Site Agreement, EPC Agreements, Supply Agreements for NSS and major equipment, Fuel Supply Agreements, O&M Agreement, Power Sales Agreements, and Interconnection Agreements as required to support Owner approvals and financing;
- Develop for NRC acceptance a Decommissioning Plan and Decommissioning Estimate; and
- Prepare a Preliminary Project Cost Estimate based on firm pricing for major equipment, budget pricing for most of the plant equipment based on preliminary design information, and indicative pricing for areas of the project subject to detailed engineering after vendor engineering data can be implemented, as well as establish formal project budgets by including allowances for uncertainty and contingencies based on risk analysis and level of pricing commitments obtained for the project

As with conceptual design, the preliminary design effort for the PBR Demonstration Plant represents a major FOAK effort. The cost of this effort is expected to be supported by stakeholders in the technology, the demonstration project, and planned subsequent applications, including the U.S. government.

The basis for preliminary engineering costs prepared for this estimate includes the following:

- Engineering effort
- Early procurements
- Project planning and management

These budgets are indicative only and can vary substantially once specific project requirements are established. An overall budget of about $116.4M is included in Table 4-7.

3.1.1.3 Final Design

Final Design for the demonstration plant is scheduled to take place over a 4 year period, during which the COL application is being reviewed by the NRC. While continuing to support licensing, the design team will complete the final design of the demonstration plant consisting of the following activities:

- Final design calculations for all design disciplines
- Grading, drainage, excavation, roadways, and site specific civil drawings
- Concrete, embedment, and structural steel drawings
- Equipment location drawings
- Piping isometrics and support details
- Connection details
- Underground utilities
- Equipment Design Drawings
- Electrical raceway, cable block, wiring diagrams
- Grounding drawings
- Lighting Drawings
- Electrical equipment layout drawings
- Pull tickets
- Instrumentation loops, logics, and elementary diagrams
- Instrument and panel layout drawings
- Communications Drawings
- Final Vulnerability Assessment and Security Plan
- Security System Drawings
- Final Fire Hazards Analysis
- Fire Detection and Suppression System Layout
- Final Safety Analysis
- Software design
- Architectural Drawings and Schedules
- Commercial Grade Dedication
- Permitting Support
- Final Intelligent 3-D CAD Model
- Construction and Equipment Procurement Specifications
- Final Construction Estimate

An overall budget of about $244.6 M is included in Table 4-7.

3.1.1.4 Nuclear Licensing

Nuclear licensing efforts include the preparation of a COL application for NRC, extended interactions with NRC to respond to technical information, implementation of special efforts to provide test data, simulation software qualification, and safety analyses. Also, NRC receives a fee for its labor, which must be paid by the COL applicant.

This budget can vary significantly once specific licensing requirements are established with NRC and project specific issues are identified. An overall budget of about $190M has be identified in Table 4-10.

3.1.1.5 Project Development

An owner entity must be formalized to complete project development, including the following:

- Development of technical and commercial project documents
- Financing agreements, including U.S. government support arrangements
- Approvals from investors, stakeholders, and regulators (as applicable), including public acceptance

A nominal allowance of $25M is included for project development in Table 4-7. This value could vary widely when ownership arrangements and a development plan are established. At this stage, it is assumed that a Public Private Partnership (PPA) will be established with some participation by BEA to initiate project development activities.

3.1.1.6 Owner Project Management

The Owner will establish a management team to provide technical and business leadership for the project in support of stakeholders. Critical technical and commercial requirements must be clearly defined in the project agreements as a basis for implementation. Considerable effort is required to plan and oversee the work within budget, schedule, quality, and licensing requirements. The Owner's management team will require senior qualified specialists in project scheduling, estimating, management, contracts, engineering, nuclear licensing, construction, operations, and public/stakeholder relations. The duration of this effort begins when the Owner is formalized during the project development process, assumed to occur at the beginning of the Preliminary Engineering effort. Therefore, Owner project management is assumed to cover a total period of 8 years during project development and beginning of commercial operations. A nominal allowance of $25M for Owner Project Management is included in Table 4-7.

3.1.2 Engineering, Procurement, and Construction

Once financing has been approved and the project is released to begin procurement and final design, the work is organized into three major EPC contracts for purposes of developing costs:

- Nuclear Steam Supply Facility (NSS)
- Energy Conversion Plant (ECP)
- Site and Balance of Plant (BOP)

Each of these EPC contracts includes major equipment, construction materials and construction labor. Complete descriptions of these facilities and the plant systems are provided in the PBR Design Description Report.

The scope of the EPC contract for the Nuclear Steam Supply scope is included in Table 3-1 below:

Table 3-1: Demonstration Plant NSS Major Items

Reflector Rods
Small Absorber Ball Systems
Pressure Vessel Units (RPU) (RPV, SG, and Cross Vessel)
Metallic Internals (RPV)

Ceramic Internals (RPV)
Circulators
Hot Gas Ducts
Pressure Relief, Pressure Controls
Steam Generator Tube Bundles
Reactor Cavity Cooling Systems
Fuel Handling and Storage
Helium Systems (He-Purification and supporting/connecting Systems)
Reactor Building
Reactor Building Annex
Reactor Auxiliary Building
Spent Fuel Storage (ISFSI)
Initial Fuel Inventory

The Energy Conversion Plant scope is included in Table 3-2 below:

Table 3-2: Demonstration Plant ECP Major Items

Interconnecting piping, valves, vents, and drains
Reboilers, vents, drains, chemical injection
Steam turbine generator with extraction ports
Steam turbine auxiliary systems
Condenser and cooling system
TG Control system
Step up transformer and HV electrical equipment
Turbine building, reboiler building
Other auxiliary and support systems

The Site and BOP Facilities scope is included in Table 3-3 below:

Table 3-3: Demonstration Plant BOP Major Items

Administration and control buildings and facilities
Power distribution
Security
Utility Systems
Yard Electrical
Pipe Racks
Gas Storage and Supply
Fire Protection Systems
Plant Water Systems
Chilled Water Systems
Cooling Water Systems

HVAC Systems
Site Preparation and Foundations
Site Development
Building foundations
Buildings & Common Facilities
Switchgear and Emergency Power Building
Central Gas Supply System Building
Control Building
Security Building and Equipment
Gatehouse
Control & Instrumentation
Plant I&C
Plant control simulator
Plant Communication
Radiation Monitoring
Fire Detection
Safeguards and Security System
Substation and Power Distribution
Plant Electrical Distribution
Uninterruptible Power Supply
Emergency Power Supply
Auxiliary Power Supply
Spare parts, warehouse, and shops
Manuals and training

3.1.3 Site Assumptions

A U.S. Gulf Coast site is used as a basis for both the Demonstration and Commercial PBR Plants with the following characteristics:

- Houston, Texas meteorology and climate characteristics (indicative of U.S. Gulf Coast)
- Barge delivery access
- Foundation conditions requiring some soil replacement and piling
- Elevation near sea level above 100 year flood level
- Low seismicity
- Good road and rail transportation access
- Available regional workforce at current rates and productivities
- No sensitive environmental or public use areas in close proximity

3.1.4 Host site interfaces

Tie-ins to host site will be via a pipe rack located within 100 m of the Plant site boundary, including the following:

- Steam delivery to host site
- Treated raw water, potable water, sewerage (raw water treatment, potable water treatment, and sewage treatment/disposal provided by host site)
- Auxiliary steam provided by host site

- Return treated condensate (condensate storage provided by host site)

The Plant site is provided based on a Host Site Agreement, which assigns responsibilities for site access, security, coordination, and safety.

Power delivery tie in is at a substation provided as part of the plant with a grid interconnection from a high voltage step up transformer, and a local host site connection from an auxiliary transformer.

A security fence is provided around the Plant with controlled security access points and shipping receiving facilities.

Controls integration with the steam host is provided through fiber optic connections with the host site facility.

3.1.5 Basis of Design

The PBR Demonstration Plant NSS and BOP are based on an HTR-Module using UCO fuel. Detailed descriptions and drawings of the HTR-Module conceptual design are provided in the PBR Design Description Report. The design heat balance provides the basis for sizing major equipment, summarized in Table 3-4.

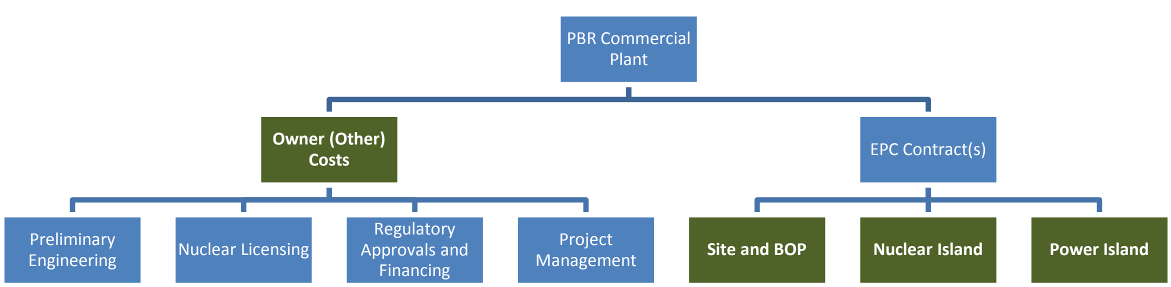
Table 3-4: Summary PBR Demonstration Plant Design Basis

Number of PBR reactors	2
Number of HTR-Modules	1
Thermal output delivered as hot helium to steam generators	400 MW_t (2 x 200 MW_t reactors)
Number of steam generators	2
Number of reboilers	2
Number of steam turbines	1

3.2 PBR Commercial Plant

The PBR Commercial Plant project is similarly organized into four major cost accounts for purposes of estimating development as shown in Figure 3-2. The conceptual engineering effort is considered an FOAK activity not needed for commercial projects and is not included. Other FOAK costs from the PBR Demonstration Plant project are eliminated as discussed in the following sections.

Figure 3-2: PBR Commercial Plant Work Breakdown



3.2.1 Owner (Other) Costs

The Owner's (non-EPC) costs for the PBR Commercial Plant exclude FOAK engineering and nuclear licensing completed for the PBR Demonstration Plant and subsequent projects. Recurring Owner's costs for commercial plants are expected to include the following:

- Project development and owner's project management
- Engineering to adapt previous designs to project-specific and site-specific requirements, to support a licensing process expected to be much more efficient than for the PBR Demonstration Plant, and to develop complete design documentation, establish major supplier and EPC agreements, and prepare comprehensive implementation plans, budgets, and schedules
- Obtaining a COL from the NRC
- Obtaining owner's regulatory and stockholder approvals and structure financing

3.2.1.1 Preliminary Design

A preliminary design effort will be required to:

- Formalize site and application requirements into Owner/off-taker agreements;
- Formalize a project specific basis of design into supply and EPC agreements using information from previous projects;
- Prepare specifications for procurement packages using information from previous projects;
- Prepare definitive technical descriptions, drawings, and diagrams to support procurement and construction planning based on provisional vendor inputs using information from previous projects;
- Define major equipment and systems sufficiently to obtain major supplier firm bids and design information to support preliminary BOP design using information from previous projects;
- Develop equipment lists, material take offs to establish preliminary construction quantities and bill of materials using information from previous projects;
- Finalize and begin implementation of project plans to fix budgets, schedules, contracting and procurements, and project management to support owner approvals and financing using information from previous projects;
- Implement plans for engineering and design configuration management and quality control using information from previous projects;
- Secure nuclear fuel supply for completion and early commercial operations;
- Finalize planning for commissioning and startup, and ITAAC compliance;
- Complete major Project Agreements, including Host Site Agreement, EPC Agreements, Supply Agreements for NSS and major equipment, Fuel Supply Agreements, O&M Agreement, Power Sales Agreements, and Interconnection Agreements as required to support Owner approvals and financing;
- Develop for NRC acceptance a Decommissioning Plan and Decommissioning Estimate using information from previous projects; and
- Prepare a Preliminary Project Cost Estimate based on firm pricing for major equipment, budget pricing for most of the plant equipment based on preliminary design information, and indicative pricing for areas of the project subject to detailed engineering after vendor engineering data can be implemented using information from previous projects, as well as establish formal project budgets by including allowances for uncertainty and contingencies based on risk analysis and level of pricing commitments obtained for the project considering experience and information from previous projects.

The basis for preliminary engineering costs prepared for this estimate includes the following:

- Engineering effort
- Early procurements
- Project planning and management

- Owner financing and approvals

These budgets are indicative only and can vary substantially once specific project requirements are established. They are based on expected efficiencies resulting from work and experience from previous projects. A budget of $143M included $43M in labor from

Table 4-22 and $100M for long lead items purchased in the preliminary phase.

3.2.1.2 Nuclear Licensing

Nuclear licensing efforts include the preparation of a COL application for NRC, extended interactions with NRC to respond to technical information, implementation of special efforts to provide test data, simulation software qualification, and safety analyses. Also, NRC receives a fee for its labor, which must be paid by the COL applicant.

An indicative nuclear licensing budget for the PBR Demonstration Plant is based on experience from other similar efforts:

This budget can vary significantly once specific licensing requirements are established with NRC and project specific issues are identified. A major increase in the efficiency of licensing activity by the project team and by NRC is assumed in this budget. An overall budget of about $91.5M is included in Table 4-22.

3.2.1.3 Project Development and Owner Project Management

The Owner will undertake project development and will establish a management team to provide technical and business leadership for the project in support of stakeholders. For NOAK projects, it is assumed that these costs will be reduced based on experience with completed projects. Critical technical and commercial requirements must be clearly defined in the project agreements as a basis for implementation. Considerable effort is required to plan and oversee the work within budget, schedule, quality, and licensing requirements. The Owner's management team will require senior qualified specialists in project scheduling, estimating, management, contracts, engineering, nuclear licensing, construction, operations, and public/stakeholder relations. The duration of this effort begins when the Owner is formalized during the project development process, assumed to occur at the beginning of the engineering effort. Therefore, Owner project management is assumed to cover a total period of 7 years during project development and through the beginning of commercial operations. Installation of eight reactors is expected to require a five year construction period after two years of engineering.

These budgets are indicative only and can vary substantially once specific project requirements are established. Project development and management requirements consider experience and information from previous projects. A budget of $25M for this effort is included in Table 4-22.

3.2.1.4 Engineering, Procurement, and Construction

Once financing has been approved and the project is released to begin procurement and final design, the work is organized into three major EPC contracts for purposes of developing costs:

- Nuclear Steam Supply (Facility) (NSS)
- Energy Conversion Plant (ECP)
- Site and Balance of Plant (BOP)

Each of these EPC contracts includes major equipment, construction materials and construction labor. Complete descriptions of these facilities and the plant systems are provided in the PBR Design Description Report.

Major items to be included in the EPC contract for the Nuclear Steam Supply scope are included in Table 3-5 below:

Table 3-5: Commercial Plant NSS Major Items

Reflector Rods
Small Absorber Ball Systems
Pressure Vessel Units (RPU)
Metallic Internals (RPV)
Ceramic Internals (RPV)
Circulators
Hot Gas Ducts
Pressure Relief, Pressure Controls
Steam Generator Tube Bundles
Reactor Cavity Cooling Systems
Fuel Handling and Storage
Helium Systems (He-Purification and supporting/connecting Systems)

The Energy Conversion Plant major items are listed in Table 3-6 below:

Table 3-6: Commercial Plant ECP Major Items

Interconnecting piping, valves, vents, and drains
Reboilers, vents, drains, chemical injection
Steam turbine generator with extraction ports
Steam turbine auxiliary systems
Condenser and cooling system
TG Control system
Step up transformer and HV electrical equipment
Turbine building, reboiler building
Other auxiliary and support systems

The Site and BOP Facilities scope is included in Table 3-7 below:

Table 3-7: Commercial Plant BOP Major Items

Administration and control buildings and facilities
Power distribution
Security
Utility Systems
Yard Electrical
Pipe Racks
Gas Storage and Supply
Fire Protection Systems

Plant Water Systems
Chilled Water Systems
Cooling Water Systems
HVAC Systems
Site Preparation and Foundations
Site Development
Building foundations
Buildings & Common Facilities
Switchgear and Emergency Power Building
Central Gas Supply System Building
Control Building
Security Building and Equipment
Gatehouse
ISFSI
Control & Instrumentation
Plant I&C
Plant Communication
Radiation Monitoring
Fire Detection
Safeguards and Security System
Substation and Power Distribution
Plant Electrical Distribution
Uninterruptible Power Supply
Emergency Power Supply
Auxiliary Power Supply

3.2.1.5 Site assumptions

The same site assumptions apply as described in Section 0 for the PBR Demonstration Plant.

3.2.1.6 Host Site Interfaces

Host site interfaces are assumed to be the as for the PBR Demonstration Plant described in Section 3.1.4.

3.2.1.7 Basis of design

The PBR Commercial Plant is based on the following plant configuration and performance.

Table 3-8: Commercial Plant Design Basis

Number of PBR units	8
Number of PBR modules	4
Thermal output delivered as hot helium to steam generators	1600 MW_t (200 MW_t per unit)
Number of steam generators	8
Number of reboilers	up to 6
Number of steam turbines	2

4.0 COST ESTIMATE DEVELOPMENT

Capital cost estimates are developed for the PBR Demonstration Plant and for a PBR Commercial Plant based on the plant descriptions and assumptions described in Sections 3.1 and 3.2 of this report. This section describes the methodology and additional assumptions used for developing these capital cost estimates.

4.1 Overall Estimating Approach

Cost estimates in this report are derived from limited cost information from previously estimated costs provided by AREVA GMBH for a demonstration plant design using an HTR-Module with two 200 MW_t reactors.

As described in Section 3.1 of this report, the PBR Demonstration Plant consists of an HTR-Module with 2 x 200 MW_t reactors, a shared control room and other nuclear island structures such as fuel storage areas. Each reactor delivers helium to a separate steam generator. Primary steam is combined from the two steam generators and delivered to a single steam turbine generator. Extraction ports from the steam turbine provide steam to two reboilers and a superheater.

As described in Section 3.2 of this report, the PBR Commercial Plant consists of the same NSS plant design as the PBR Demonstration Plant improved by experience from a series of projects. The PBR Commercial Plant is defined to be four 2-reactor HTR-Modules on a site, taking advantage of sharing and learning from the other units.

At this stage of study, estimating is limited to an indicative, pre-commercial estimate, which reflects major equipment and engineering budgets obtained for the nuclear steam supply system derived from previous work in Germany in 1991.

NSS costs were derived from the engineering and equipment budgets from the 1991 German work, escalated to 2011 dollars using a conversion factor of 0.6 USD per DM, and 2.56%/year inflation escalation. Construction materials and construction labor for the nuclear steam supply area were derived by factoring such costs from equipment costs, by estimating building volumes and concrete volumes from drawings, and by scaling similar costs from earlier work done for the NGNP Program and other projects. Equipment, construction materials and construction labor costs were derived by factoring using ratios from other nuclear projects.

ECP and BOP costs were scaled from other projects based major equipment performance requirements established by the estimated heat balance. Equipment, construction materials, and labor costs were derived by scaling information from other projects.

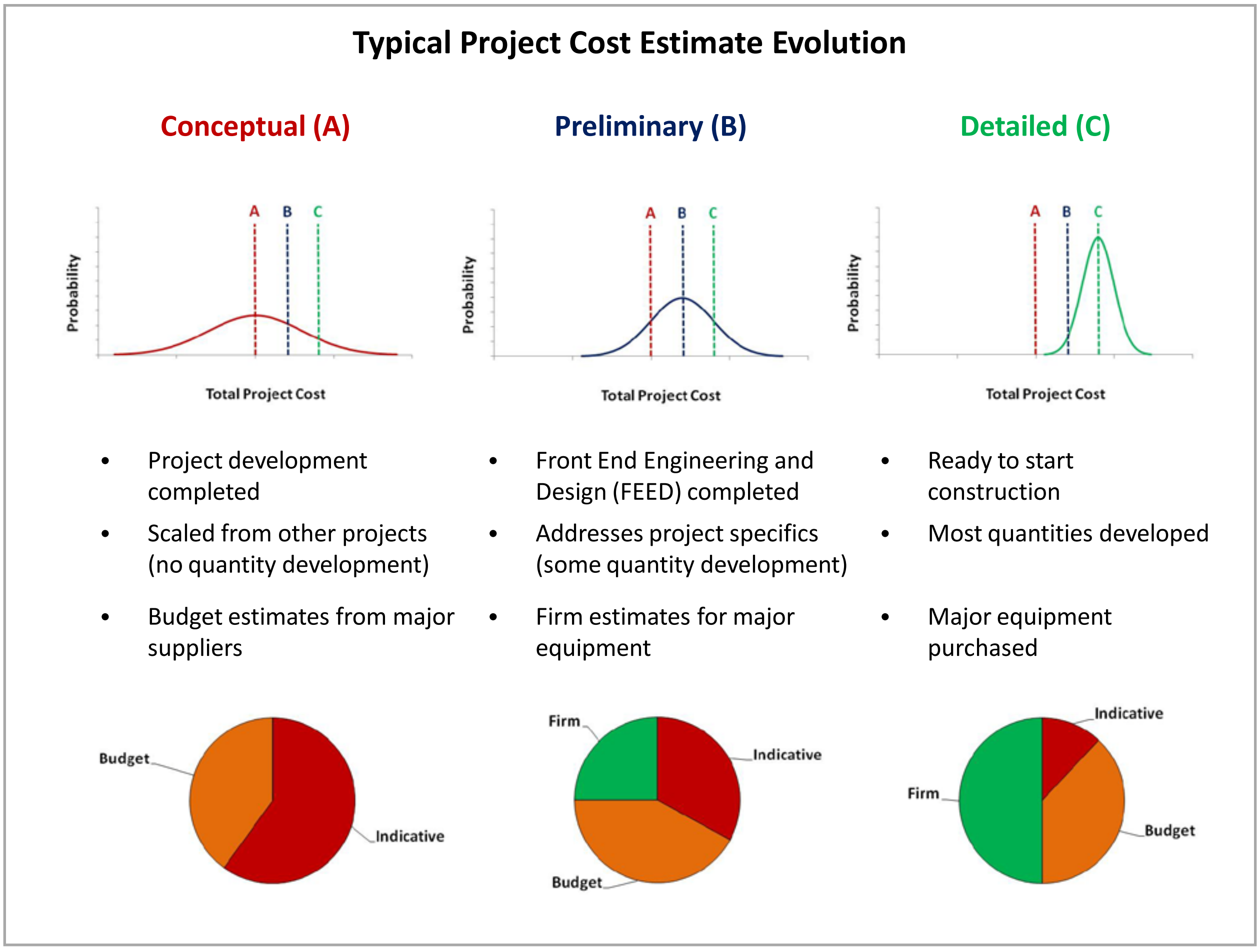
No supplier budget pricing was obtained given the short duration of this review.

Figure 4-1 illustrates a typical sequence where conceptual, preliminary, and detailed cost estimates evolve for a project as engineering is completed and progressively more pricing is firmed up with suppliers and contractors.

Point “A” represents a conceptual project cost estimate based on indicative and budget pricing, with a confidence level of roughly ±30%. Point “B” represents a preliminary project cost estimate where 25% of the scope is supported by firm pricing for major equipment, with a confidence level on the order of ±20%. Point “C” represents a final cost estimate where roughly half of the scope is supported by firm pricing and most of the rest by budget pricing with a confidence level approaching ±10%. Allowances are included in the conceptual and preliminary estimates to cover scope and commercial uncertainties in an effort to represent point “C.”

The current stage of work for the PBR design is considered “Pre-conceptual” with no budget pricing from suppliers and only indicative budgeting derived from other projects.

Figure 4-1: Major Project Estimating Stages



4.2 Construction and Engineering Labor

The construction labor rate used to translate construction labor hours to construction costs is $71.23/hr. This construction labor rate is for construction in the U.S. Gulf Coast (USGC) and is a weighted contracted wage rate based on a 40 hour work week that includes the base wage rate, benefits, taxes and insurance, distributables, and supervision for each class of laborer as detailed in Table 4-1.

Table 4-1: Basis for Average Construction Labor Rate

US$/hr	% of Workforce	Base Wage	Benefits	Tax and Insurance	Distributables, Supervision, and Overhead	Total
Boilermaker	20%	27.63	13.96	7.22	46.11	94.92
Carpenter	10%	24.25	7.29	6.96	35.04	73.54
Electrician	15%	22.78	7.82	6.85	34.00	71.45
Operator-over 150 tons	1%	26.15	7.95	7.11	37.87	79.07
Operator-under 150 tons	1%	25.15	7.95	7.03	36.76	76.89
Ironworker	20%	19.91	7.32	6.63	30.28	64.14
Laborer	15%	15.00	2.77	6.25	19.86	43.88
Painter	3%	15.88	4.32	6.32	22.54	49.06
Pipefitter	15%	24.09	9.68	6.95	37.49	78.21
			Weighted Contracted Wage Rate			**71.23**

Key elements of this labor rate are as follows:

- Gulf Coast hourly wage rates and fringe benefits for construction crafts; note the total of these is fixed by the December 3, 2010 Davis Bacon General Decision in Louisiana (case 100016)
- Cost for federal and state unemployment benefits and federal insurance (social security and medicare)
- Subcontractor construction distributables and indirect costs excluding profit (e.g., field office, temporary facilities, construction equipment, scaffolding and small tools, other distributables, supervision, and overhead)
- Percentage use of each construction craft (to develop an average project construction labor rate)

This data was then used to calculate the following:

- Straight time direct hire and subcontracted hourly labor cost by craft
- Direct hire and subcontracted overtime hourly rates by craft for time and a half and double-time
- Direct hire and subcontracted average hourly rates by craft for 50 hour and 60 hour work weeks assuming time and a half for hours over 40
- Subcontracted average hourly rates by craft for 70 hour work week
- Percentage use weighted subcontracted average hourly craft labor rates for 40, 50, 60 and 70 hour work weeks
- Total project weighted average hourly subcontracted labor rate for 40, 50, 60 and 70 hour work weeks

For a 40 hour work week, the gulf coast average labor rate for direct hire construction is $37.32/hour. The overall contractor would add construction distributables, heavy hauls, start up and testing, other construction indirects, overhead, and profit to develop the total project erection labor cost.

The average hourly cost for a subcontracted construction approach is $71.23/hour for a 40 hour work week and $73.62/hour for a 50 hour work week. To develop a total project erected labor cost, subcontractor profit and general contractor costs (supervision, heavy haul, start up and testing, other indirects, overhead, and profit) must be added.

The assumed engineering labor rate is $125/hr. The engineering labor rate is used to calculate the preliminary, conceptual, and final engineering costs based on the engineering labor hour estimates conducted for each of the engineering stages. Note that preliminary and conceptual design engineering costs are FOAK costs included in Other Plant Costs for the PBR Demonstration Plant, while the final design and construction support engineering costs are included in the NSS, ECP, and BOP EPC estimates for both the PBR Demonstration Plant and the Commercial Plant.

4.3 PBR Demonstration Plant Economics (FOAK Cost Analysis)

For the purposes of this assessment, it is assumed that the NGNP Demonstration Plant will be located on the U.S. Gulf Coast (USGC). It will serve to demonstrate a full scale PBR NSS module, an ECP sized for the full thermal output of the NSS and the associated site and BOP facilities. A full scope of costs are addressed, including engineering, nuclear licensing, environmental permitting, fuel, and operations and maintenance through an initial three-year period needed to demonstrate operability and performance.

4.4 PBR Demonstration Plant Capital Cost

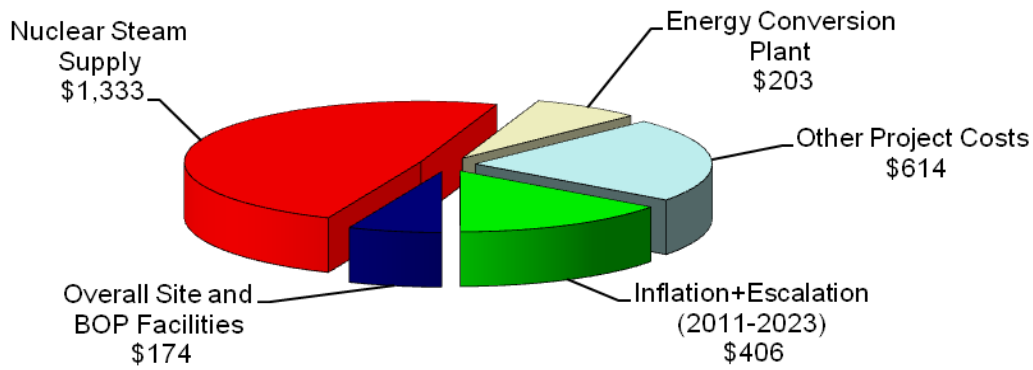
EPC costs for these three plant areas are presented along with key assumptions and the basis for cost estimate development. The assumed average labor rates are $71.23/hr for construction labor and $125/hr for engineering. An EPC fee of 5% is also included for each of the three EPC contracts. Final design and construction support engineering costs are included in each of the EPC contracts, while preliminary and conceptual design engineering costs are included in Other Plant Costs.

Table 4-2 and Figure 4-2 summarize the total capital costs for the PBR NGNP Demonstration Project. These costs are presented in 2011 U.S. dollars, except for the inflation component which converts the 2011 dollars to as-spent nominal dollars. Capital costs are assumed to grow at the rate of inflation with no additional escalation. This assumption is consistent with the expectation that current prices for materials and equipment include the impact of demand from China and other emerging, high growth markets and that current commodity prices will not escalate significantly above inflation between now and when materials and equipment for the PBR Demonstration Plant are procured.

Table 4-2: PBR Demonstration Plant Capital Cost Summary

DESCRIPTION	Total
EPC CONTRACTS	**$1000's**
Overall Site and BOP Facilities	174,118
Nuclear Steam Supply	1,333,220
Energy Conversion Plant	202,653
Total EPC Contracts	**1,709,991**
Other Project Costs	613,882
Subtotal	**2,323,874**
Inflation+Escalation (2011-2023)	406,329
Total Project Cost	**2,730,203**

Figure 4-2: PBR Demonstration Plant Capital Cost Summary



Total Cost $2,730M (Costs are in $M)

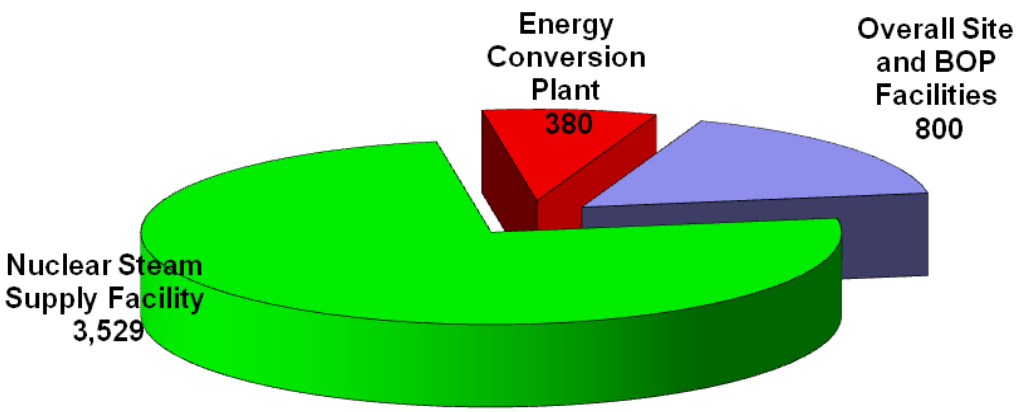
The capital costs are dominated by the NSS costs. For the PBR Demonstration Plant, other project costs, which include FOAK costs such as conceptual and preliminary engineering, and licensing, are also significant. The capital costs are shown on a per unit thermal energy basis in Table 4-3.

Table 4-3: PBR Demonstration Plant Capital Cost per Unit Energy

DESCRIPTION	Total
EPC CONTRACTS	**$/kWt**
Overall Site and BOP Facilities	435
Nuclear Steam Supply	3,333
Energy Conversion Plant	507
Total EPC Contracts	**4,275**
Other Project Costs	1,535
Subtotal	**5,810**
Inflation+Escalation (2011-2023)	1,016
Total Project Cost	**6,826**

Construction labor hours are estimated based on relationships between equipment, material, and labor costs on similar projects, and can vary widely with site and project requirements. The construction labor is dominated by the NSS labor as shown in Figure 4-3. Overall, the split between direct material costs and direct labor costs is about 70% material and 30% labor.

Figure 4-3: PBR Demonstration Plant Construction Manhours



(Labor is in thousands of manhours)

4.4.1.1 PBR Demonstration Plant NSS Capital Cost

The NSS represents the areas of the plant associated with the reactor, steam generator, and support systems plus the associated structures. The initial fuel load and heavy component transport costs are also included. The overall NSS cost is estimated based on the descriptions provided in PBR Design Description Report.

NSS costs were derived from the engineering and equipment budgets from the 1996 German work, escalated to 2011 dollars. An additional allowance of 10% was added as an FOAK item to major components costs for re-establishing vendor capabilities in the supply chain. Construction materials and construction labor for the nuclear steam supply area were derived by factoring such costs from equipment costs, by estimating building volumes and concrete volumes from drawings, and by scaling similar costs from earlier work done for the NGNP Program and other projects. Equipment, construction materials, and construction labor costs were derived by factoring using ratios from other nuclear projects.

A nominal EPC contingency of 10% is included in the estimate to represent the uncertainty and risk associated with the EPC contracts when the project is implemented. This can vary widely depending on specific project requirements and commercial arrangements. This level of contingency assumes that the equipment costs adapted from the German HTR-Module designs are reasonably accurate and conservative, as well as the factored estimates for materials and labor. At this stage there is no basis to establish a higher contingency since no major deficiencies or omissions have been identified in the basis for these estimates.

The EPC cost for the NSS is summarized in Table 4-4.

Table 4-4: PBR Demonstration Plant EPC Cost for NSS

DESCRIPTION	Material $1000's	Labor $1000's	Total $1000's	Field Hrs 1000's
Final Design			167,940	
Construction Support Engineering			72,660	
Construction Directs	530,418	200,787	731,205	2,819
Commissioning/Startup	136,944	50,572	187,516	710
Other		-	-	
EPC Contingency			115,932	
EPC Fee			57,966	
Total Nuclear Steam Supply Facility			**1,333,220**	

The split between construction material and labor direct costs is 73% material cost and 27% labor cost.

Major elements of cost included in the estimate are as follows:

- Reactor System
  - Reflector Rods
  - Small Absorber Ball System
  - Pressure Vessel Unit (RPU)
  - Ceramic Internal (RPV)
  - Metallic Internal (RPV)
  - Circulator
  - Hot Gas Duct
  - Misc materials
- Steam Generator
  - Tube Bundle
  - Misc Materials
- Main Support Systems
  - Pressure Relief, Pressure Control
  - Cavity Cooler
  - Fuel Handling and Storage
  - Helium systems
  - Superior Component Engineering
  - Measuring Systems
  - Misc Materials
- Buildings & Common Facilities (incl. foundations)
  - Spent Fuel Storage Building
  - Reactor Building
  - Reactor Building Annex
  - Reactor Auxiliary Building

4.4.1.2 PBR Demonstration Plant ECP Capital Cost

The capital cost for the Energy Conversion Plant (ECP) was estimated based on recent experience in conventional power plant construction. The scope of the ECP includes major equipment described in the ECP scope (primarily the steam turbine generator and the cooling system) plus the ECP building and related items.

ECP costs were scaled from other projects based major equipment performance requirements established by heat balance calculations. Equipment, construction materials, and labor costs were derived by scaling information from other projects.

No EPC contingency is included in this estimate because the ECP is a conventional design with much more experience and less uncertainty than the NSS.

The EPC cost for the Energy Conversion Plant is summarized in Table 4-5.

Table 4-5: PBR Demonstration Plant EPC Estimate for ECP

	Material	Labor	Total	Field Hrs
DESCRIPTION	**$1000's**	**$1000's**	**$1000's**	**1000's**
Final Design			44,280	
Construction Support Engineering			53,760	
Construction Directs	67,922	25,616	93,538	360
Commissioning/Startup	-	-	-	-
Other	-	1,425	1,425	20
EPC Fee			9,650	
Total Energy Conversion Plant			**202,653**	

The split between construction material and labor direct costs is 71% material cost and 29% labor cost.

Material costs and associated erection manhours were developed for the FOAK and NOAK ECPs. The FOAK is comprised of piping to and from nozzles two steam generators(included in NSS estimate), a nominal 150 MW single extraction condensing steam turbine, condenser, wet mechanical draft cooling tower, high pressure and low pressure reboiler system to produce the high pressure and low pressure process steam using the heat in the steam turbine extraction steam.

The NOAK design is comprised of two trains. Each train includes four steam generators (Included in NSS) with an extraction condensing steam turbine, condenser, wet mechanical draft cooling tower and a high pressure low pressure reboiler system to produce process steam.

The ECP cost included the following equipment/systems (note: the cost of the steam generators is included in the nuclear steam supply system cost):

- STG Vendor Package
    - Steam Turbine/Generator
    - Generator Synchronizing Equipment
    - Generator Protection & Metering
    - Transformer Protection & Metering
- STG Balance of Plant
    - T-G Gland Seal and Exhaust System

    - Condensate System
    - Drains to Condenser
    - Nitrogen System
    - Hydrogen System
    - CO2 System
    - Lube Oil Conditioning System
    - Fire Protection System
- Steam Generators Balance of Plant
    - Main Steam System
    - LP Steam System
    - Feedwater heating system including deaerator
    - Steam Line Blowout System
    - Steam Generator Feed Water Pumps
    - Steam Generator Vents & Drains System
    - Steam Generator Boiler Chemical Feed
    - Steam/Water Sampling System
- Process Steam System
    - Reboilers
    - Process Steam Piping
    - Process Water inlet Piping
- Electrical and Instruments and Controls
    - ISO Phase Bus Duct
    - Segregated Phase Bus Duct
    - Electrical Conduit and Connection
    - Instruments and Controls
    - Cooling System
    - Condenser Plus Air Removal and Cleaning Systems
    - Circulating Water System
    - Auxiliary Cooling Water System
    - Wet cooling Tower
- Site Development
    - Transformer Foundations
    - Miscellaneous Equipment Foundations
    - Steam Turbine Generator Foundation
    - Buildings and Structures
    - Reboiler Building
    - Turbine Building

The equipment/material costs and associated manhours for each item were developed using the following information:

- Late 2006 ECP Estimate developed for the 2007 PCDR. These costs were for an ECP capacity using a single 220 MW steam turbine.
- Recent Fossil Plant Project Estimates
- Reboiler System Cost developed for the comparable cogeneration facility

The PCDR estimate was based on an air-cooled condenser and direct extraction steam design. The estimate was capacity factored to the nominal 150 MW FOAK ECP steam turbine capacity and then escalated from late 2006 to December 2010. Cost and manhours for equipment/systems from recent Shaw combined cycle steam bottoming cycle and fossil plant steam cycle estimates were then capacity factored and compared with the factored/escalate PCDR data to confirm that the costs/manhours were reasonable.

The air cooled condenser was replaced with a surface condenser and wet cooling tower. The equipment/material cost and labor manhours for these items were factored from a recent combined cycle indicative estimate with a bottoming cycle close to the required ECP capacity.

The reboiler system cost and labor hours were developed by factoring and escalating the Ravenswood estimate.

The NOAK present day material and labor hour costs were scaled from the FOAK information.

4.4.1.3 PBR Demonstration Plant Overall Site and BOP Facilities Capital Cost

The cost estimate of the overall site and BOP facilities was based on the pre-conceptual design definition and prior experience in the construction of power and process projects. Some of the cost allowances for this portion of the project were derived from other projects for which detailed costs were readily available.

Estimate components were derived as follows:

- Modularization experience in the petrochemical and in the new nuclear construction projects of recent years.
- BOP buildings costs were factored from other buildings from recent power plant projects and scaled based on square-footage assumptions typical for the expected structures.
- No estimate for the onsite switchyard is provided it is assumed this will be provided by the host site.
- Offsite road development is not included.
- Water and Waste water treatment equipment costs are not included. It is assumed that these are to be provided by the host site to meet process steam purity requirements, and site specific discharge restrictions.

No EPC contingency is included in this estimate because the BOP is a conventional design with much more experience and less uncertainty than the NSS.

The EPC cost for the overall site and BOP facilities is summarized in Table 4-6.

Table 4-6: PBR Demonstration Plant Capital Cost Summary – Overall Site and BOP Facilities

DESCRIPTION	Material $1000's	Labor $1000's	Total $1000's	Field Hrs 1000's
Final Design			32,400	
Construction Support Engring			18,480	
Construction Directs	57,984	51,388	109,371	721
Commissioning/Startup	-	5,576	5,576	78
Other	-	-	-	-
EPC Fee			8,291	
Total Site and BOP			**174,118**	

The split between construction material and labor direct costs is 50% material cost and 50% labor cost.

Major elements of cost in the BOP as are as follows:

- Auxiliaries
  - Utility Systems
  - Yard Electrical
  - Pipe Racks
- Site Preparation and Foundations
  - Site Development
  - Dewatering system
- Buildings & Common Facilities
  - Switchgear and Emergency Supply Building
  - Operations Building
  - Security Building
  - Gatehouse
- Control & Instrumentation
  - Environmental Monitoring
  - Radiation Monitoring(site)
  - Security System
  - Plant I&C
  - Simulator
- Substation and Power Dist
  - Plant Electrical
  - Yard Electrical

4.4.1.4 Other PBR Demonstration Plant Capital Costs

Other project costs include engineering, nuclear licensing, and other activities needed to secure the site, establish site access, provide site interconnections, and undertake project implementation. Other costs for the NGNP Demonstration Project are summarized in Table 4-7.

Table 4-7: PBR Demonstration Plant Capital Cost Summary - Other Project Costs

DESCRIPTION			$1000's
Conceptual Design			
Conceptual Design - Site and BOP			4,140
Conceptual Design - NSS			16,200
Conceptual Design - ECP			4,860
Subtotal - Conceptual Design			**25,200**
Preliminary Design			
Preliminary Design - Site and BOP			16,800
Preliminary Design - NSS			78,600
Preliminary Design - ECP			21,000
Subtotal - Preliminary Design			**116,400**
Final Design (included in EPC)			
Final Design - Site and BOP			32,400
Final Design - NSS			167,940
Final Design - ECP			44,280
Subtotal - Final Design			**244,620**
Project Management			**25,000**
PPP/BEA Project Dev & Admin			**25,000**
Nuclear licensing and Permitting			**190,070**
Com'l Plant FOAK Design & Certification			**100,000**
Owners Startup Costs			
Training			0
Startup			21,552
			21,552
Subtotal - Other Project Costs			**503,222**
EPC Contracts			1,709,991
Total Project Cost w/o Contingency			**2,213,213**
Project Contingency	5%		110,661
Total Other Project Costs			**613,882**

The design estimates include the engineering costs associated with the support of licensing. This cost can be found in the licensing section below.

Each category of other project costs is discussed in more detail below.

Project Engineering and Design Estimates

Project engineering and design estimates include conceptual design criteria reconciliation, preliminary, and final stages. The conceptual and preliminary project engineering and design estimates are FOAK costs, while the final estimates support construction and are included with the EPC contracts for both FOAK and NOAK plants. Project engineering and design estimates are shown in Table 4-8 and summarized in Figure 4-4. An engineering labor rate of $125/hr is assumed.

It is assumed that significant effort will be required to adapt the German HTR-Module design to U.S. Standard and to update the safety analysis to U.S. Regulatory requirements. The FOAK engineering estimate is based on discipline staffing levels required over the project schedule that is influenced substantially by the licensing activities along the critical path. It conservatively assumes that most of preliminary and final engineering and design will require significant reworking to conform to U.S. and site specific requirements. The degree of rework has not been assessed in detail.

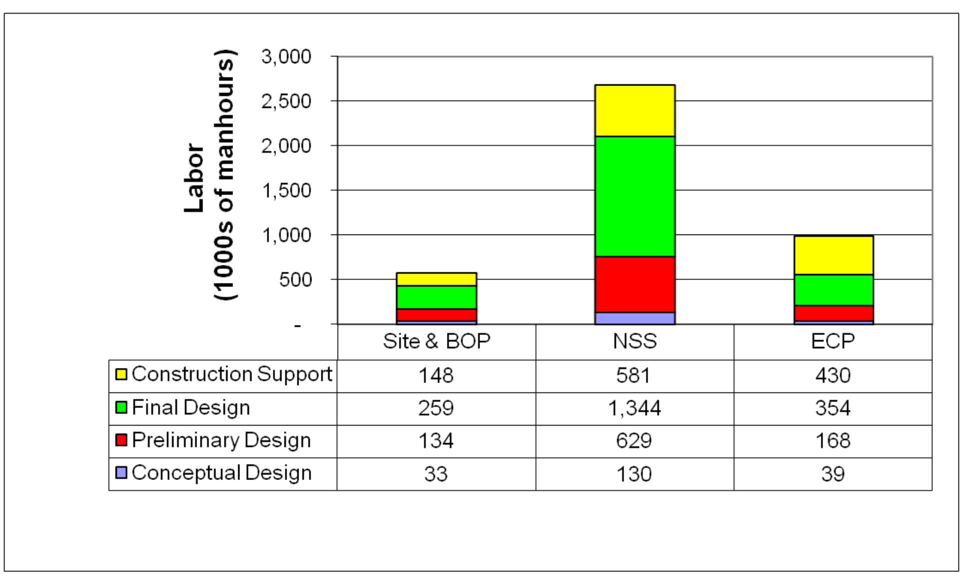
The value in kind for the previously performed engineering work on the HTR-Module has not been evaluated. This value will eventually have to be determined.

Table 4-8: PBR Demonstration Plant Engineering and Design Estimates

				Construction
	Conceptual	**Preliminary**	**Final***	**Support**
DESCRIPTION	**$1000's**	**$1000's**	**$1000's**	**$1000's**
Site & BOP	4,140	16,800	32,400	18,480
NSS	16,200	78,600	167,940	72,660
ECP	4,860	21,000	44,280	53,760
Total	25,200	116,400	244,620	144,900
				Construction
	Conceptual	**Preliminary**	**Final***	**Support**
Description	**1000's hrs**	**1000's hrs**	**1000's hrs**	**1000's hrs**
Site & BOP	33	134	259	148
NSS	130	629	1,344	581
ECP	39	168	354	430
Total	202	931	1,957	1,159

*Final design and engineering in support of construction are included with the EPC contracts

Figure 4-4: PBR Demonstration Plant Project Engineering and Design Estimates Summary



Research and Development

R&D costs are not included in this cost estimate, as they are not considered part of the capital cost of the plant. R&D costs such as graphite and fuel qualification should be considered in addition to the costs presented in this report. Vendor development costs for major NSS components, such as circulator development, are included in the NSS cost estimate as part of equipment cost. The majority of the plant outside of the reactor and fuel is conventional and thus requires no significant technology development or R&D.

Project Development, Management, Technology Certification, and Startup

The Owner's Project Management costs are included with an allowance of $25M that covers a management team for the entire period of Preliminary Design through operation of the NGNP Demonstration Project. PPP/BEA Project Development and Management costs have also been included with an allowance of $25M.

Startup costs not included in the EPC costs for each facility include twelve months of fixed O&M, representing the plant O&M staff as they participate in testing and turnover and complete the training process before commissioning.

Costs have been included for FOAK commercial plant reference design and certification of a standard NSS. The PBR Commercial Plant design and licensing will build upon the HTR-Module estimate experience plus the lagging interactive experience with the NGNP design and licensing development. The focus of this FOAK design and licensing effort is the NRC approval of a reference NSS design that is applicable for multi-modules, process heat applications and an envelope of site parameters. This effort is projected to culminate a few years after the startup and testing of the NGNP and is viewed as the key to broad commercial deployment - the purpose of the NGNP. The estimate for this effort is highly speculative and will depend heavily on the success of managing technology development and forming effective interactions between the NGNP and commercial plant development efforts. An allowance of $100M is included as the current estimate for this effort. Costs associated with technology rights are not included in this estimate, as they can vary widely based on commercial arrangements and are assumed to be well within the margin of certainty of the estimates in this report.

Finally, an nominal Owner's Project Contingency of 5% is added to the Total Project Cost to cover the unanticipated problems, errors, and delays that occur in any project assuming the project is well defined and supported with appropriate agreements and contracts.

The uncertainty range for all of the Other Project costs cannot be determined because nominal allowances are used for Owner's costs. For purposes of this evaluation the uncertainty range is considered to be ±40%.

The Project Development, Management, Startup and Certification costs plus the Owner's Project Contingency are included in Table 4-9.

Table 4-9: PBR Demonstration Plant Project Development, Management, Technology Certification, and Startup Costs

DESCRIPTION	$1000's
Project Management	25,000
PPP/BEA Project Dev & Admin	25,000
Com'l Plant FOAK Design & Cert.	100,000
Startup	21,552
Project Contingency	110,661
	282,212

Licensing

The schedule and cost estimates for NGNP licensing and environmental permitting are based on the following assumptions:

- The PBR pre-application and design certification reviews have proceeded to the extent that technical design, safety analysis, and policy issues for PBR are well understood and the course of action for resolution with NRC has been developed by the time it is necessary to prepare the NGNP license applications,
- The NGNP COL pre-application review period results in a clear path towards resolving the design, safety, and policy issue differences relative to the PBR design, including for example:
    - Additional qualification testing required for fuel and graphite,
    - Other materials and component testing related to the higher temperatures for NGNP (e.g., heat exchanger materials),
    - The means by which the ECP and BOP interfaces with the NSS and resolution of related safety analysis issues,
    - Design, safety, and operational issues that are not addressed in a design certification review, but which must be addressed for a non-LWR COL (e.g., environmental, LWA, and Owner issues).
- NGNP design development, safety analysis, and site engineering have proceeded to the extent that a satisfactory NGNP licensing application(s) can be prepared,
- Costs for any additional NGNP testing (e.g., fuel qualification, other R&D) are covered elsewhere, and corresponding schedule requirements for inputs to the COL application are understood,
- NGNP engineering groups have prepared the site drawings and other materials necessary to prepare State and Local permit applications,
- NRC provides the necessary priority attention and resources to conduct the review of the NGNP plant as they would any LWR application for construction,
- The licensing estimate does not include general project or contract management costs incurred by the NGNP Commercial Alliance and the U.S. Department of Energy, which are covered in the Project Development and Administration costs,
- NRC review and inspections through the full-power test that is part of the NGNP Project startup program are included in this cost estimate,
- Federal environmental permitting costs are included in the preparation and NRC review of the ESP; State and Local environmental permitting costs are estimated separately,
- Costs related to licensing of fuel transportation and on-site handling are not included since a specific site has not yet been determined,
- NRC review of the plant simulator and operator training is covered elsewhere,
- The NRC review cost estimates are based on a current NRC labor rate of $256/hour whereas the average rate for preparing the submittals is based on $125/hr.

As indicated in the previous sub-section, the NGNP licensing and cost estimates are based on a successful PBR U.S. NRC design certification pre-application program and also a successful NGNP COL pre-application program, both of which are reflected in the development of an NGNP Licensing Review Basis document.

The schedule accounts for licensing pre-application interactions, COLA preparation, NRC review, and plant construction and startup inspections. Licensing costs resulting from engineering support, which includes support for development of topical reports and preparation of technical information for licensing are included in the engineering estimates.

Additional licensing costs including NRC fees and project management are also estimated. The PM and technical costs are those incurred by the project team to manage the licensing interactions, develop licensing and regulatory management plans, and administrate the development of licensing documentation. A summary of the major licensing costs are presented in Table 4-10. The engineering support costs associated with development are included with the other direct licensing costs to indicate the total licensing cost.

Table 4-10: PBR Demonstration Project Nuclear Licensing Costs

	Cost ($1000)
Pre-application and COLA preparation**	**$92,000**
PM and technical	$25,000
Legal	$700
NRC Fees	$15,000
Engineering Support*	$51,300
NRC Review**	**$90,900**
PM and technical	$8,000
Legal	$4,000
NRC Fees	$60,000
Engineering Support*	$18,900
Construction**	**$44,340**
PM and technical	$6,000
Legal	$2,000
NRC Fees	$25,000
Engineering Support*	$11,340
State/Local Permits**	**$3,720**
PM and technical	$2,300
Legal	$50
NRC Fees	$20
Engineering Support*	$1,350
Initial Operation**	**$48,210**
PM and technical	$25,000
Legal	$4,000
NRC Fees	$13,000
Engineering Support*	$6,210
Total Licensing	**$190,070**
Total Engineering Support (included in total engineering cost estimate)	**$89,100**
Grand Total (including direct licensing and engineering support)	**$279,170**

*Engineering costs for licensing support were built up in the engineering estimates and are included in the engineering estimate totals.
**Totals for each category include engineering support.

4.4.2 PBR Demonstration Plant O&M

4.4.2.1 PBR Demonstration Plant Overall Staffing

Fixed O&M costs were calculated based on estimates of permanent site staffing, planned maintenance, and planned capital replacements for each of the main plant systems. Fixed O&M was applied annually regardless of plant capacity factor.

Variable O&M was calculated based on consumables and costs incurred hourly when the plant is operating at full capacity. Variable costs for each plant system were applied based on the number of hours the plant was expected to be operating.

The O&M labor costs were calculated by applying representative labor rates by category for power industry operators and maintenance personnel. Labor staffing for the plant is shown in Table 4-11. Additional training staff is included to account for the services to future commercial plant operators. An allowance of 30% of staffing salaries is included for supervision, plus another 30% for overhead and Operating Contractor's fee. Supervision adds roughly 15% of total staff.

Table 4-11: PBR Demonstration Plant Staffing Requirements

Staffing	Number	Shifts	Employees
NSS operators	3	4	12
NSS maint. personnel	6	1	6
ECP operators	2	4	8
ECP maint personnel	3	1	3
Security personnel	8	4	32
NSS Eng'g (day)	8	1	8
ECP Eng'g (day)	1	1	1
BOP Eng'g (day)	1	1	1
Quality personnel	1	1	1
Safety	4	1	4
Training personnel	1	1	1
Technicians	6	2	12
Support personnel	6	1	6
Supervision			14
Total			109

4.4.2.2 PBR Demonstration Plant NSS O&M Cost

The fixed and variable O&M costs for the NSS are included in Table 4-12.

Table 4-12: Demonstration Plant NSS O&M Costs

	Total $k/yr
NSS operators	2,496
NSS maint. personnel	998
NSS Eng'g (day)	1,664
Planned Maintenance	598
Decommissioning Fund Payments	549
NRC Fees	3,000
Total fixed O&M - NSS	9,305
	$/hr
Helium	5
Solid Waste Disposal	50
Spent Fuel Disposal Payment	152
Total Variable Cost - NSS	207

4.4.2.3 PBR Demonstration Plant ECP O&M Cost

O&M costs for the ECP are included in Table 4-13. Only fixed O&M costs are assigned to the ECP area.

Table 4-13: Demonstration Plant ECP Fixed O&M Costs

	Total $k/yr
ECP operators	1,498
ECP maint personnel	499
ECP Eng'g (day)	208
Planned Maintenance	450
Total fixed O&M - ECP	2,655

4.4.2.4 PBR Demonstration Plant Overall Site and BOP Facilities O&M Cost

O&M costs for BOP facilities are included in Table 4-14. Primarily fixed O&M costs are assigned to the BOP facilities area.

Table 4-14: Demonstration Plant Overall Site and BOP O&M Costs

	Total $k/yr
Security personnel	5,325
BOP Eng'g (day)	208
Quality personnel	187
Training personnel	208
Safety personnel	666
Technicians	1,747
Support personnel	749
Planned Maintenance	29
Training Materials	100
Allowance for Unplanned Repairs	402
Total fixed O&M - BOP	9,621
	$/hr
Other Waste Disposal	50
Total variable O&M - BOP	50

4.4.2.5 PBR Demonstration Plant O&M Cost Summary

An overall summary of the fixed and variable O&M costs for the PBR Demonstration Plant are included in Table 4-15. Planned Maintenance includes the expected lifetime replacements of the circulators, graphite reflectors, fuel handling systems, and overhauls of the turbine generators.

Table 4-15: PBR Demonstration Plant O&M Costs

Fixed O&M	$k/yr
Plant staffing	16,453
Planned Maintenance	1,048
Training Materials	100
Decommissioning Fund Payments	549
Allowance for Unplanned Repairs	402
NRC Fees	3,000
Total fixed O&M	21,552
Variable O&M	$/hr
Helium	5
Solid Waste Disposal	50
Spent Fuel Disposal Payment	152
Other Waste Disposal	50
Total Variable Cost	257

4.4.3 PBR Demonstration Plant Fuel Cycle Cost

Fuel costs were developed based on input from B&W and AREVA. B&W developed the fabrication costs based on the cost to license, build, and operate a fuel fabrication facility to support the PBR Demonstration Plant. AREVA estimated the cost of enriched UO_3 to be provided to the B&W facility.

The PBR Demonstration Plant is assumed to have 720,000 pebbles per module or 360,000 pebbles per reactor for initial cores. The initial core pebbles are assumed to have 3.4 grams of uranium per pebble and use 8% enriched uranium. The supplied cost for this fuel is estimated to be $190/pebble. This cost is included in the NSS capital estimate.

The PBR Demonstration Plant is assumed to have yearly reload quantities of 150,000 pebbles per module or 75,000 pebbles per reactor. The reload pebbles are assumed to have 7.0 grams of uranium per pebble and use 14% enriched uranium. The supplied cost for this fuel is estimated to be $201/pebble. This cost is included in the project cash flow.

The values are reported as an average assuming fuel is fabricated over a 13 year fuel delivery schedule which includes both the demonstration plant and subsequent commercial plant deliveries. Estimated costs are on an annual basis assuming a consistent Uranium throughput. The fixed annual cost is not dependent on the loading for an individual pebble (3.4 grams U for the IC pebble and 7 grams U for each reload pebble) but rather the total quantity of uranium expected to be processed in a year. These fixed annual costs include the following:

- Depreciation of capital over a 20 year period
- Maintenance and associated parts
- Labor (direct and indirect) plus associated overhead.
- Recovery of Uranium Scrap
- Transportation costs between NFS and NOG-L
- Utilities
- Non-Uranium purchased components
- Accrued D&D costs
- G/A

Capital costs in the cost basis include:

- Major equipment acquisition
- Efforts to procure, install and shake down new equipment
- Completion of Bay 15A at the NOG-L site
- Design and licensing of a shipping container capable of transporting 3 loaded fuel blocks.
- Procurement of shipping containers.

Fuel costs include transportation and delivery. Uranium losses of 1% of total delivered quantity are also assumed in the cost basis.

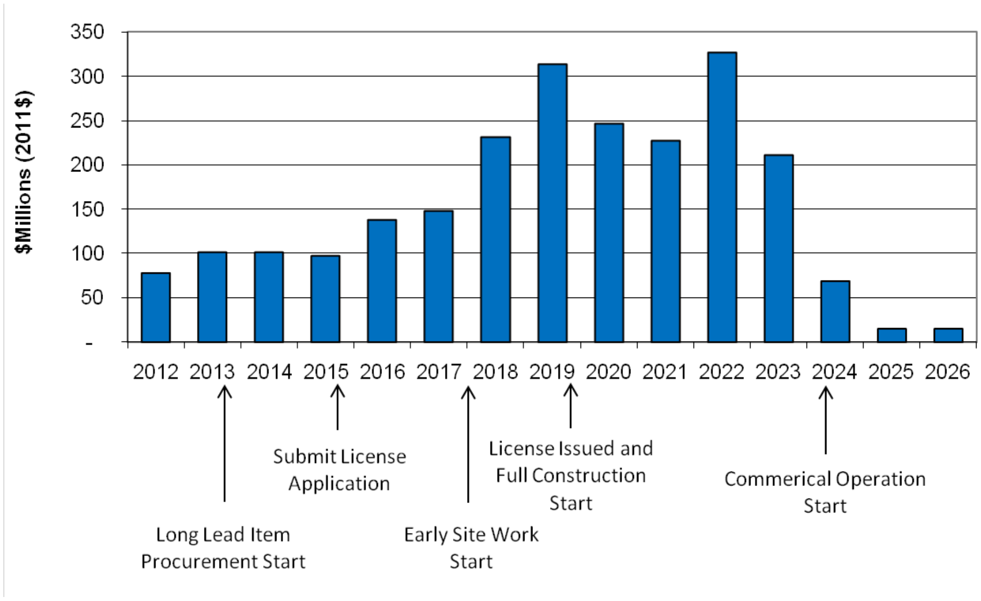
4.4.4 PBR Demonstration Plant Cost Cash Flow

Cash flow projections were calculated through the first three years of operation. The projections are based on the following assumptions:

- General Inflation Rate 2.0%/year
- Real Escalation Rates
    - Capital Cost 0.0%/year
    - O&M Cost 0.0%/year
    - Nuclear Fuel 0.5%/year
- First year availability/utilization
    - 90% capacity factor

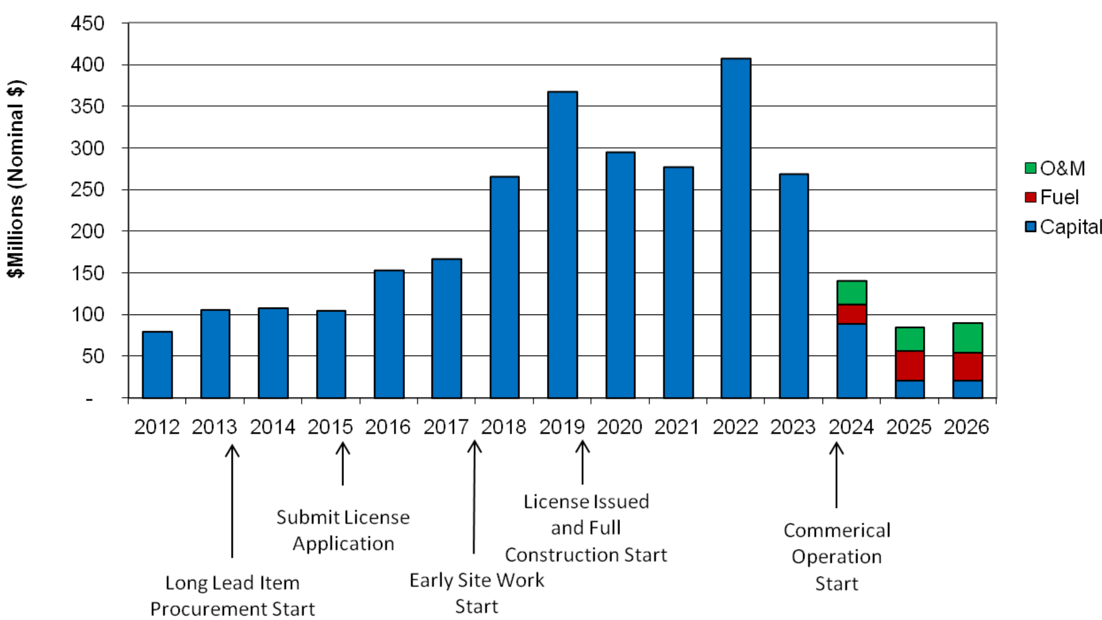
The construction cost expenditures are shown in real 2011 dollars in Figure 4-5.

Figure 4-5: PBR Demonstration Plant Construction Cost Expenditures



The overall cost cash flows in nominal dollars, which include capital cost and fuel and O&M for the operational years, are shown in Figure 4-6. These cost cash flows assume that the project is directly funded and that a loan is not necessary (and thus interest during construction and debt service do not appear in the operational cash flows).

Figure 4-6: PBR Demonstration Plant Cost Cash Flows



4.5 Commercial Plant Economics (NOAK Cost Analysis)

For the purposes of this assessment, it is assumed that the PBR Commercial Plant will be located on the USGC. It utilizes a full scale HTR-Module with experience from similar projects, an ECP sized for the full thermal output of the NSS and the associated BOP facilities. A full scope of costs is addressed, including engineering, nuclear licensing, environmental permitting, fuel, and operations and maintenance through the life of the project.

4.5.1 Commercial (NOAK) Plant Capital Cost

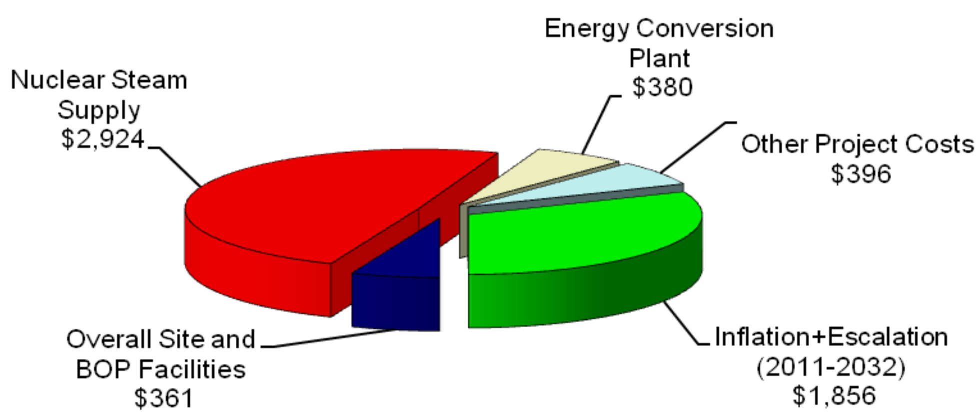
EPC costs for the NSS, BOP, and ECP of the Commercial Plant are presented along with key assumptions and the basis for cost estimate development. The assumed average labor rates are $71.23/hr for construction labor and $125/hr for engineering. Final design and construction support engineering costs and an EPC fee of 5% are included in each of the three EPC contracts.

Table 4-16 and Figure 4-7 summarize the total capital costs for the PBR Commercial Plant Project. These costs are presented in 2011 U.S. dollars, except for the Inflation component which converts the 2011 dollars to as-spent nominal dollars. Note that because the Commercial Plant Project is not expected to be in operation until 9 years after the Demonstration Plant, additional inflation is included.

Table 4-16: Summary of Commercial Plant Project Cost

DESCRIPTION	Total
EPC CONTRACTS	**$1000's**
Overall Site and BOP Facilities	361,351
Nuclear Steam Supply	2,923,815
Energy Conversion Plant	380,473
Total EPC Contracts	**3,665,638**
Other Project Costs	396,450
Subtotal	**4,062,089**
Inflation+Escalation (2011-2032)	1,855,608
Total Project Cost	**5,917,696**

Figure 4-7: Summary of Commercial Plant Project Cost



Total Cost $5,918M (Costs are in $M)

The cost per commercial (NOAK) module is assumed to be the average cost per module of the Commercial Plant, which consists of four modules of two reactors each. A summary of the cost per commercial module is shown in Table 4-19.

Table 4-17: Summary of Commercial Plant Module Cost

DESCRIPTION	Total
EPC CONTRACTS	**$1000's**
Overall Site and BOP Facilities	90,338
Nuclear Steam Supply	730,954
Energy Conversion Plant	95,118
Total EPC Contracts	**916,410**
Other Project Costs	99,113
Subtotal	**1,015,522**
Inflation+Escalation (2011-2032)	463,902
Total Cost Per Module	**1,479,424**

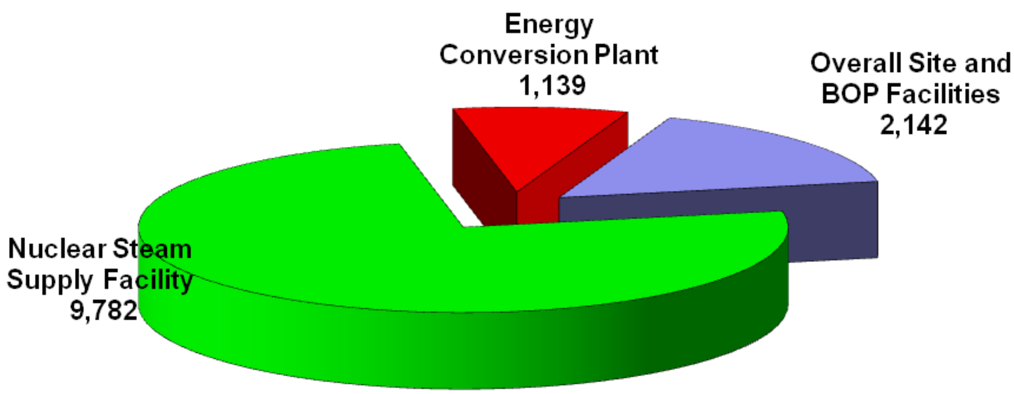
Capital costs on a per unit thermal energy basis are shown in Table 4-20.

Table 4-18: Commercial Plant Capital Costs on a per Unit Energy Basis

DESCRIPTION	Total
EPC CONTRACTS	**$/kWt**
Overall Site and BOP Facilities	226
Nuclear Steam Supply	1,827
Energy Conversion Plant	238
Total EPC Contracts	**2,291**
Other Project Costs	248
Subtotal	**2,539**
Inflation+Escalation (2011-2032)	1,160
Total Cost Per kWt	**3,699**

The overall Commercial Plant construction labor is dominated by the NSS as shown in Figure 4-8. Overall, the split between direct material costs and direct labor costs is about 69% material and 31% labor. Labor estimates are indicative only and can vary widely based on site and project conditions, and construction methods, extent of modularization and other conditions at the time of the project.

Figure 4-8: Commercial Plant Construction Manhours



(Figure Note: Labor is in thousands of manhours)

4.5.1.1 Commercial Plant NSS Capital Cost

The commercial NOAK design is comprised of eight reactor/steam generators arranged in 4 Nuclear Island HTR-Modules serving two steam turbine generators. Each of the two trains includes four steam generators (included in NSS) with a single extraction condensing steam turbine and associated BOP. The design of the steam turbine and reboilers that provide steam to the host site will vary widely by site and application. In some cases the steam turbine may be eliminated with steam from the steam generators used directly in reboilers to make process steam. Many process host sites utilize high quality steam to operate existing steam turbine drives for mechanical drives and power generation. Since the ECP represents a small fraction of the plant cost, variation in ECP designs should not substantially impact the representative economics contemplated in this review.

The scope and the method for generating the estimate is derived from that of the PBR Demonstration Plant; however, some cost reductions were taken to account for the effects of learning and elimination of FOAK items required to be in the PBR Demonstration Plant but not the Commercial Plant. This combination of factors has been assumed to result in an aggregate reduction of 30%, applied to material/equipment cost and labor cost for all NSS SSC items

The 10% increment applied for major component cost to account for reestablishing the supply chain for the PBR Demonstration Plant has been deducted for the Commercial Plant. It is assumed that a mature supply chain will be available.

The EPC cost for the Commercial Plant NSS is included in Table 4-19.

.

Table 4-19: Commercial Plant EPC Cost for Nuclear Steam Supply Facility

DESCRIPTION	Material $1000's	Labor $1000's	Total $1000's	Field Hrs 1000's
Final Design			24,660	
Construction Support Engineering			91,260	
Construction Directs	1,322,058	555,146	1,877,204	7,794
Commissioning/Startup	407,722	141,602	549,323	1,988
Other		-	-	
EPC Contingency			254,245	
EPC Fee			127,122	
Total Nuclear Steam Supply Facility			**2,923,815**	

The split between construction material and labor direct costs is about 71% material cost and 29% labor cost.

4.5.1.2 Commercial Plant ECP Capital Cost

The NOAK design is similar to the FOAK. The NOAK is comprised of two trains. Each train includes four steam generators (included in NSS) with an extraction condensing steam turbine, condenser, wet mechanical draft cooling tower and a high pressure low pressure reboiler system to produce process steam.

The EPC cost for the Commercial Plant ECP is included in Table 4-20.

Table 4-20: Commercial Plant EPC Estimate for Energy Conversion Plant

DESCRIPTION	Material $1000's	Labor $1000's	Total $1000's	Field Hrs 1000's
Final Design			31,320	
Construction Support Engineering			40,320	
Construction Directs	209,568	79,011	288,578	1,109
Commissioning/Startup	-	-	-	-
Other	-	2,137	2,137	30
EPC Fee			18,118	
Total Energy Conversion Plant			**380,473**	

The split between construction material and labor direct costs is 72% material cost and 28% labor cost.

4.5.1.3 Commercial Plant Overall Site and BOP Facilities Capital Cost

The EPC cost for the Commercial Plant BOP is included in Table 4-21.

Table 4-21: Commercial Plant Capital Cost Summary – Overall Site and BOP Facilities

DESCRIPTION	Material $1000's	Labor $1000's	Total $1000's	Field Hrs 1000's
Final Design			36,720	
Construction Support Engineering			21,840	
Construction Directs	133,013	135,487	268,501	1,902
Commissioning/Startup	-	17,083	17,083	240
Other	-	-	-	-
EPC Fee			17,207	
Total Site and BOP			**361,351**	

The split between construction material and labor direct costs is 47% material cost and 53% labor cost.

4.5.1.4 Other Commercial Plant Project Cost

Many of the costs shown for PBR Demonstration Plant such as conceptual design, preliminary design, project development and administration, and FOAK design and certification are not included in for the Commercial Plant because those cost items were FOAK items. Other Commercial Plant Project costs are summarized in Table 4-22. Design estimates include the engineering required to support licensing.

Table 4-22: Summary of Other Commercial Plant Project Costs

DESCRIPTION	$1000's
Preliminary Design - Site and BOP	18,000
Preliminary Design - NSS Facility	11,280
Preliminary Design - ECP	14,400
Project Development and Management	25,000
Nuclear Licensing and Permitting	91,480
Land	2,000
Startup	40,858
Project Contingency	193,433
Total Other Project Costs	396,450

4.5.2 Commercial Plant O&M

The Commercial Plant O&M is assumed to be similar to the PBR Demonstration Plant but with a smaller staff per PBR module due to sharing between the modules and learning.

4.5.2.1 Overall Commercial Plant Staffing

The Commercial Plant staffing requirements are included in Table 4-23.

Table 4-23: Commercial Plant Staffing Requirements

Staffing	Number	Shifts	Employees
NSS operators	8	4	32
NSS maint. personnel	16	1	16
ECP operators	4	4	16
ECP maint personnel	4	1	4
Security personnel	20	4	80
NSS Eng'g (day)	8	1	8
ECP Eng'g (day)	1	1	1
BOP Eng'g (day)	1	1	1
Quality personnel	4	1	4
Safety	4	1	4
Training personnel	2	1	2
Technicians	5	4	20
Support personnel	6	1	6
Supervision			29
Total			223

4.5.2.2 Commercial Plant NSS O&M Cost

The fixed and variable O&M costs for the NSS are included in Table 4-24.

Table 4-24: Commercial Plant NSS O&M Costs

	Total $k/yr
NSS operators	6,656
NSS maint. personnel	2,662
NSS Eng'g (day)	1,664
Planned Maintenance	1,838
Decommissioning Fund Payments	549
NRC Fees	4,000
Total fixed O&M - NSS	17,369
	$/hr
Helium	5
Solid Waste Disposal	50
Spent Fuel Disposal Payment	152
Total Variable Cost - NSS	207

4.5.2.3 Commercial Plant ECP O&M Cost

O&M costs for the ECP are included in Table 4-25. Only fixed O&M costs are assigned to the ECP area.

Table 4-25: Commercial Plant ECP O&M Costs

	Total $k/yr
ECP operators	2,995
ECP maint personnel	666
ECP Eng'g (day)	208
Planned Maintenance	40
Total fixed O&M - ECP	3,909

4.5.2.4 Commercial Plant Overall Site and BOP Facilities O&M Cost

O&M costs for BOP facilities are included in Table 4-26. Primarily fixed O&M costs are assigned to the BOP facilities area. Cooling and makeup water costs are assumed to be included as part of the process facility.

Table 4-26: Commercial Plant Overall Site and BOP O&M Costs

	Total $k/yr
Security personnel	13,312
BOP Eng'g (day)	208
Quality personnel	749
Training personnel	416
Safety personnel	666
Technicians	2,912
Support personnel	749
Planned Maintenance	66
Training Materials	100
Allowance for Unplanned Repairs	402
Total fixed O&M - BOP	19,580
	$/hr
Other Waste Disposal	50
Total variable O&M - BOP	50

4.5.2.5 Commercial Plant O&M Cost Summary

An overall summary of the fixed and variable O&M costs for the Commercial Plant are included in Table 4-29.

Table 4-27: Summary of Commercial Plant O&M Costs

Fixed O&M	$k/yr
Plant staffing	33,862
Planned Maintenance	1,944
Training Materials	100
Decommissioning Fund Payments	549
Allowance for Unplanned Repairs	402
NRC Fees	4,000
Total fixed O&M	40,858
Variable O&M	$/hr
Helium	5
Solid Waste Disposal	50
Spent Fuel Disposal Payment	152
Other Waste Disposal	50
Total Variable Cost	257

4.5.3 Commercial Plant Fuel Cycle Cost

The Commercial Plant is assumed to have 720,000 pebbles per module or 360,000 pebbles per reactor for initial cores. The initial core pebbles are assumed to have 3.4 grams of uranium per pebble and use 8% enriched uranium. The supplied cost for this fuel is estimated to be $142/pebble.

The Commercial Plant is assumed to have yearly reload quantities of 150,000 pebbles per module or 75,000 pebbles per reactor. The reload pebbles are assumed to have 7.0 grams of uranium per pebble and use 14% enriched uranium. The supplied cost for this fuel is estimated to be $156/pebble.

The values are reported as an average assuming fuel is fabricated over a 13 year fuel delivery schedule which includes both the demonstration plant and subsequent commercial plant deliveries. Estimated costs are on an annual basis assuming a consistent Uranium throughput. The fixed annual cost is not dependent on the loading for an individual pebble (3.4 grams U for the IC pebble and 7 grams U for each reload pebble) but rather the total quantity of uranium expected to be processed in a year. These fixed annual costs include the following:

- Depreciation of capital over a 20 year period
- Maintenance and associated parts
- Labor (direct and indirect) plus associated overhead.
- Recovery of Uranium Scrap
- Transportation costs between NFS and NOG-L
- Utilities
- Non-Uranium purchased components
- Accrued D&D costs
- G/A

Capital costs in the cost basis include:

- Major equipment acquisition
- Efforts to procure, install and shake down new equipment
- Completion of Bay 15A at the NOG-L site
- Design and licensing of a shipping container capable of transporting 3 loaded fuel blocks.

- Procurement of shipping containers.

Fuel costs include transportation and delivery. Uranium losses of 1% of total delivered quantity are also assumed in the cost basis.

4.5.4 Commercial Plant Lifecycle Economics

Process heat applications for the PBR Commercial Plant can vary widely in terms of how steam from the NSSS is utilized to produce electricity and process steam. This means that the ECP design can range from using large steam turbine generators with small amounts of steam extraction feeding small reboilers, to a very small topping steam turbine generator, or no steam turbine at all for cases where the host site demands high pressure steam for utilization in its existing steam turbines for driving mechanical equipment and generators. If most of the steam is utilized to produce electricity, the economic analysis tends to resemble that of a power generation unit competing with power available from the grid or onsite power generation. As the use of steam shifts from power to process steam export, the cost of steam turbine and related equipment is reduced while the cost of reboilers and high energy pipe increases. Although the equipment costs may change from application to application, the total costs of the ECP and BOP are expected to not to change dramatically and are a relatively small portion of the total capital relative to the NSSS.

Most large industrial, chemical and petrochemical facilities that constitute the potential market for large onsite cogeneration applications have existing integrated steam systems using high, intermediate and low pressure steam currently supplied by process heat recovery boilers and combustion turbines with heat recovery boilers. As a host to a PBR Commercial Plant, they are likely to define an interface based primarily on steam output with power generation considered secondary in the design of a plant. Industrial combustion turbine cogeneration units are designed and dispatched to provide reliable steam supply for large process production units and operate in coordination with other steam supply sources based on heat recovery from various process units. Electrical power production from the combustion turbines is used or sold as necessary, but normally considered as a secondary factor in design or dispatch.

In order to represent a true process heat application, the PBR Commercial Plant is adapted to produce high energy steam for the host facility with no electrical power generation. This provides a representative case which brackets the range of application conditions. The other extreme, producing only electrical power, is not considered a process heat application and is not developed for this study.

Lifecycle economics are modeled for the PBR Commercial Plant versus a gas fired cogeneration unit producing the same amount of steam from heat recovery steam generators. Results of this comparison suggest the PBR Commercial Plant generally provides steam at costs comparable to what can be provided with a conventional combustion turbine cogeneration unit burning natural gas in the $10-12/MMBtu range. These results are sensitive to a number of assumptions, and consider that the combustion turbines produce a large amount of electric power in addition to providing process steam. It is expected that optimizing the PBR Commercial Plant application design based on site specific conditions will result in lower breakeven gas costs by providing the best combination of steam and power. Since no specific site or application basis was provided for this analysis, this economic comparison is considered a “worst case” scenario since the opportunity

Representative lifecycle economics are developed for the PBR Commercial Plant to provide an indication of future economic competitiveness with conventional process heat systems. The lifecycle economics consider steam revenues and capital recovery, fuel, O&M, electricity, and decommissioning costs. The performance in terms of output, utilization, and efficiency are also important to the lifecycle economics. The Commercial Plant must be able to compete against alternative cogeneration plants over its lifetime.

Natural gas fired cogeneration plants dominate the cogeneration market in the United States and in the face of future carbon regulation and seemingly abundant domestic shale gas reserves, natural gas fired plants are expected to remain the reference conventional cogeneration plant design before the 2032 timeframe in which the first

Commercial Plant is projected to begin commercial operation. Therefore, the lifecycle economics of the Commercial Plant are based on a comparison with those of a natural gas fired cogeneration plant that produces the same amount and quality of steam.

4.5.4.1 Commercial Plant Output

The saleable plant outputs are high pressure (HP) export steam, intermediate pressure (IP) steam and low pressure (LP) export steam. By matching steam outputs from the nuclear and conventional steam supply systems, the need to assign value to steam is avoided. A small mismatch in LP export steam is disregarded to simplify the comparison considering the high levels of uncertainty associated with the evolution of the details of the nuclear island performance.

The outputs of the Commercial Plant are calculated and shown in the energy balance summary in Table 4-32. For this assessment the representative configuration chosen has no steam turbines and only produces steam for export. Note that the average per reactor column is for the total Commercial Plant configuration. The average per reactor is simply calculated by dividing the Commercial Plant energy values by the total number of reactors (two reactors per module, four modules for a total of eight reactors for the Commercial Plant).

Table 4-28: PBR Demonstration Plant Energy Balance Summary

	Total Commercial Plant	**Average Per Reactor**
Nuclear Fuel Heat Input	1600 MW_t	200 MW_t
Reactor Losses	3.2 MW_t	0.4 MW_t
Circulator Heat Added	18 MW_t	2.3 MW_t
Process Heat	*1615 MW_t*	*202 MW_t*
Gross Power Output	0 MWe	0 MW_e
Internal Loads	-19.2 MW_e	-2.4 MW_e
Net Power	*-19.2 MW_e*	*-2.4 MW_e*
HP Export Steam	*1676 tonnes/h @ 510 °C and 9.06 MPa*	*210 tonnes/h @ 510 °C and 9.06 MPa*
IP Export Steam	*183 tonnes/h @ 271 °C and 1.83 MPa*	*23 tonnes/h @ 271 °C and 1.83 MPa*
LP Export Steam	*45 tonnes/h @ 177 °C and 0.38 MPa*	*5.6 tonnes/h @ 177 °C and 0.38 MPa*

4.5.4.2 Commercial Plant Utilization

For the lifecycle economic comparison a lifetime average capacity factor of 90% was assumed. This lifetime average capacity factor takes into account the planned and forced outages and capacity derates throughout the life of the plant and a simplifying assumption applies the average capacity factor to each year of plant operation.

4.5.4.3 Lifecycle Economic Comparison to Natural Gas-Fired Cogeneration Plant

The lifecycle economics of the Commercial PBR Plant are compared to that of a natural gas fired cogeneration plant. Cost and performance assumptions for the natural gas fired plant are developed from experience with recent similar projects, using consistent assumptions to build up the material, labor, and indirect costs. Performance estimates were developed from a heat balance for a natural gas fired cogeneration plant that exports the same amount of HP and IP steam to the host facility through a pipe rack. Natural gas fired cogeneration plants include combustion turbines with fixed power output. In the economic comparison, replacement power charged to the PBR Commercial Plant compensate for the additional power produced by the combustion turbines in the conventional cogeneration case. The lifetime average capacity factor for the natural gas fired cogeneration plant was assumed to be the same as the PBR Commercial Plant. By matching the steam outputs, the value of the export steam no longer needs to be accounted for as it will have the same value for both of the options being compared. It is difficult to account for the value of process steam given the variety of sources and inability to isolate related costs. The difference in LP steam export is neglected considering the low value of this steam and the uncertainty in how future PBR reactor output estimates will evolve.

The performance and cost assumptions used in the lifecycle economic comparison are summarized in Table 4-33.

Table 4-29: Summary of Lifecycle Economic Comparison Performance and Cost Assumptions

	Combined Cycle Gas Turbine Cogeneration	**PBR Commercial Plant**
Configuration	6 GE 7FA Version 5 Cogeneration Units	4 Commercial Modules (8 Reactors)
Net Thermal Capacity	3646 MW_t	1600 MW_t
Net Electric Capacity	1207 MW_e	-19 MW_e
HP Steam Export	3695 klb/h (1676 tonnes/h)	3695 klb/h (1676 tonnes/h)
IP Steam Export	404 klb/h (183 tonnes/h)	404 klb/h (183 tonnes/h)
LP Steam Export	317 klb/h (144 tonnes/h)	98 klb/h (45 tonnes/h)
CO_2 emissions	612 tonnes/hr	0 tonnes/hr
Lifetime Average Capacity Factor	90%	90%
Total Capital Cost (EPC, Owner’s, Project Contingency, and Construction Interest)	$1,136M (2011 dollars)	$4,849M (2011 dollars)
Fixed O&M	$\$20/kW_t{\cdot}yr$	$\$26/kW_t{\cdot}yr$
Variable O&M	$\$1.9/MW_t{\cdot}h$	$\$0.2/MW_t{\cdot}h$

Key economic assumptions used in the lifecycle economic comparison are summarized below. These economic assumptions are representative of current similar projects. Notably the replacement electricity cost is based nominally on future projected electricity prices considering the economics of a large natural gas fired combined cycle plant and other existing and new power generation sources in the USGC region. The initial natural gas price range is representative of natural gas prices seen in the last five years, and the initial carbon penalty range represents at the low end, no mandated carbon regulations and at the high end, the cost of compliance with fossil fuel plants. Key lifecycle economic assumptions include;

1. All costs are in 2011 U.S. dollars and each new plant is assumed to begin commercial operation in 2032, to allow a consistent basis for comparison.
2. 2% annual general inflation rate with real annual escalation rate assumptions as follows:

a. Capital – 0%
b. Nuclear Fuel Price – 0.5%
c. Natural Gas Price – 2%
d. Carbon Penalty – 1%
e. O&M Cost – 0%
f. Replacement Electricity Cost– 1%

3. Financial and economic parameters

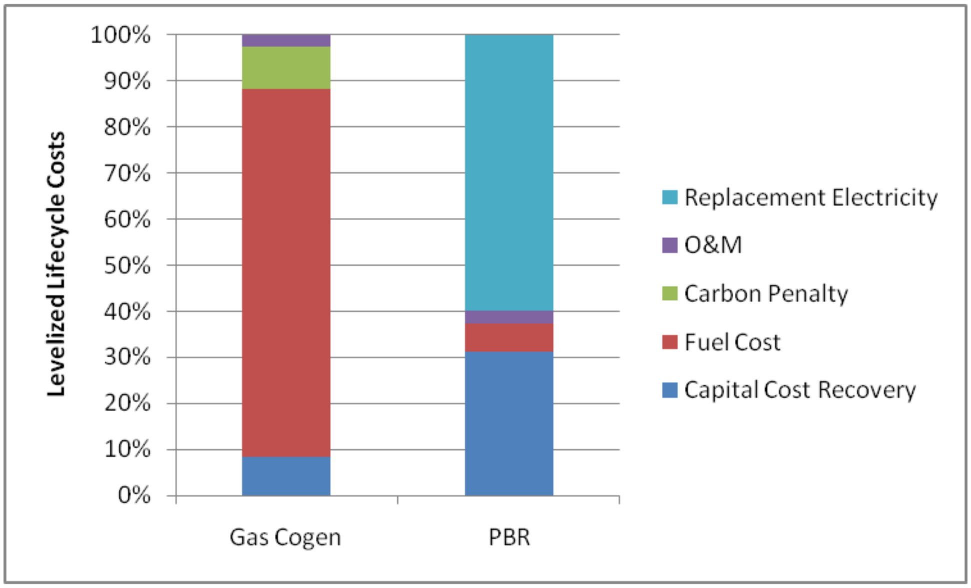
a. Economic life – 40 years
b. Effective income tax rate – 38.9%
c. MACRS depreciation schedule
d. Debt/equity ratio – 50/50
e. Real equity return – 12%
f. Real debt interest return – 7.5%
g. Real discount rate – 8.3%
h. Annual real fixed capital charge rate – 11%

4. Initial prices (when the plant begins operation in 2032 in 2011 dollars)

a. Replacement electricity cost – $90/MW·h
b. Natural gas price – $3/MMBtu – $15/MMBtu
c. Carbon penalty – $0/tonne CO_2 – $50/tonne CO_2

Figure 4-9 presents a comparison of the components that make up the lifecycle costs for the PBR Commercial Plant and a conventional natural gas fired cogeneration plant, assuming a 40 year life, with gas price set at the breakeven point of $10.56/MMBtu and a carbon penalty of $25/tonne CO_2. The figure shows that capital recovery is the dominant component of the PBR plant lifecycle cost while fuel is the dominant component of the gas cogeneration plant lifecycle cost. Replacement electricity is used to equate the outputs of the two plants and is large for PBR because of the large amount of electricity the gas cogeneration plant produces along with the steam.

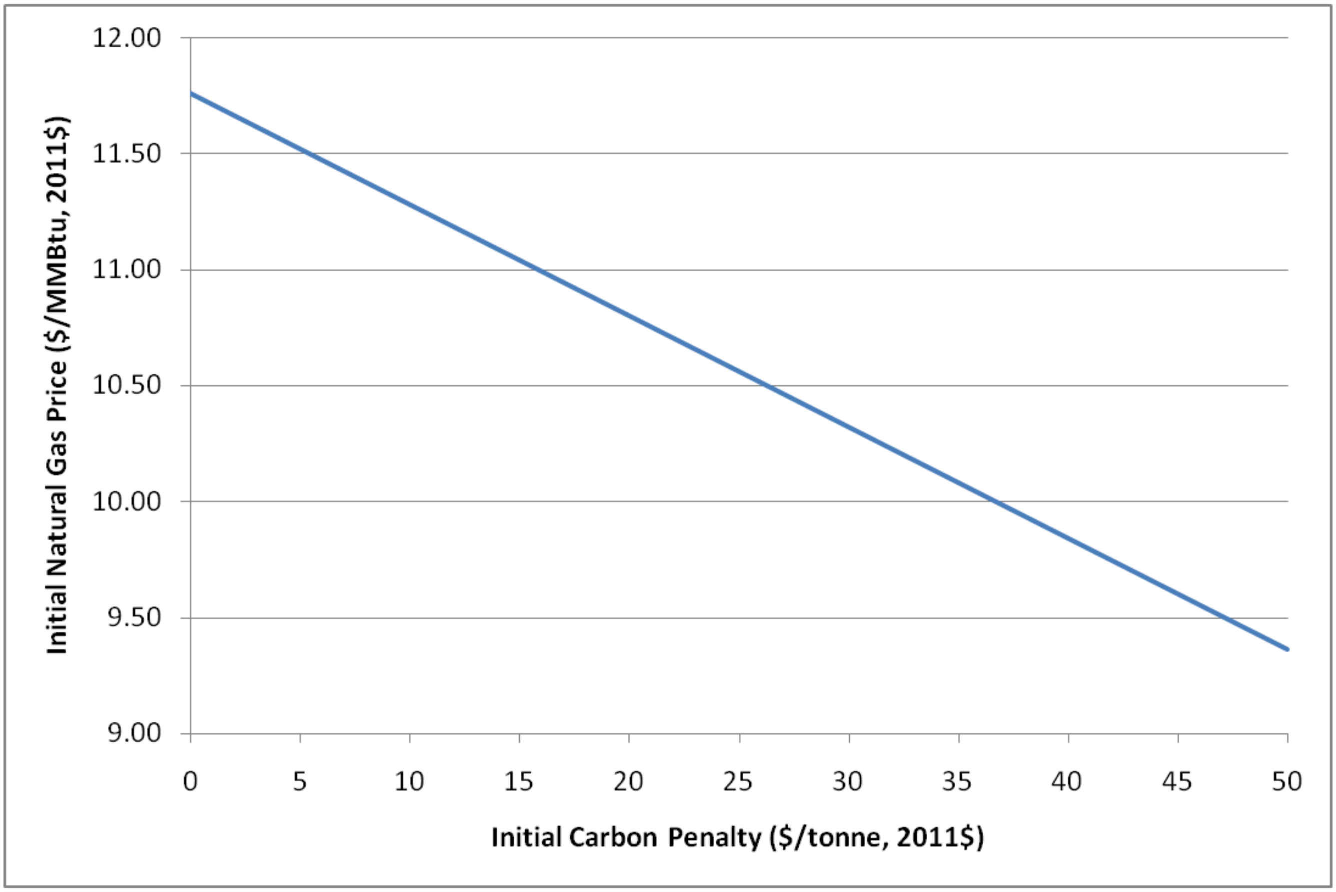
Figure 4-9: Lifecycle Cost Comparison of PBR Commercial Plant versus Gas Fired Cogeneration Plant



Because of the high level of uncertainty that surrounds both future natural gas prices and future carbon penalties, these parameters were used as sensitivities. The breakeven natural gas price is the initial natural gas price (at the start of commercial operation in 2032 in 2011 dollars) that results in the commercial PBR and the natural gas fired cogeneration plant having the same lifecycle economic value (the same net present value of costs and revenues over the lives of the projects). Natural gas prices above the breakeven price result in the PBR Commercial Plant being more economical than the gas cogeneration plant; therefore, the economics of the PBR improve with decreasing breakeven natural gas price.

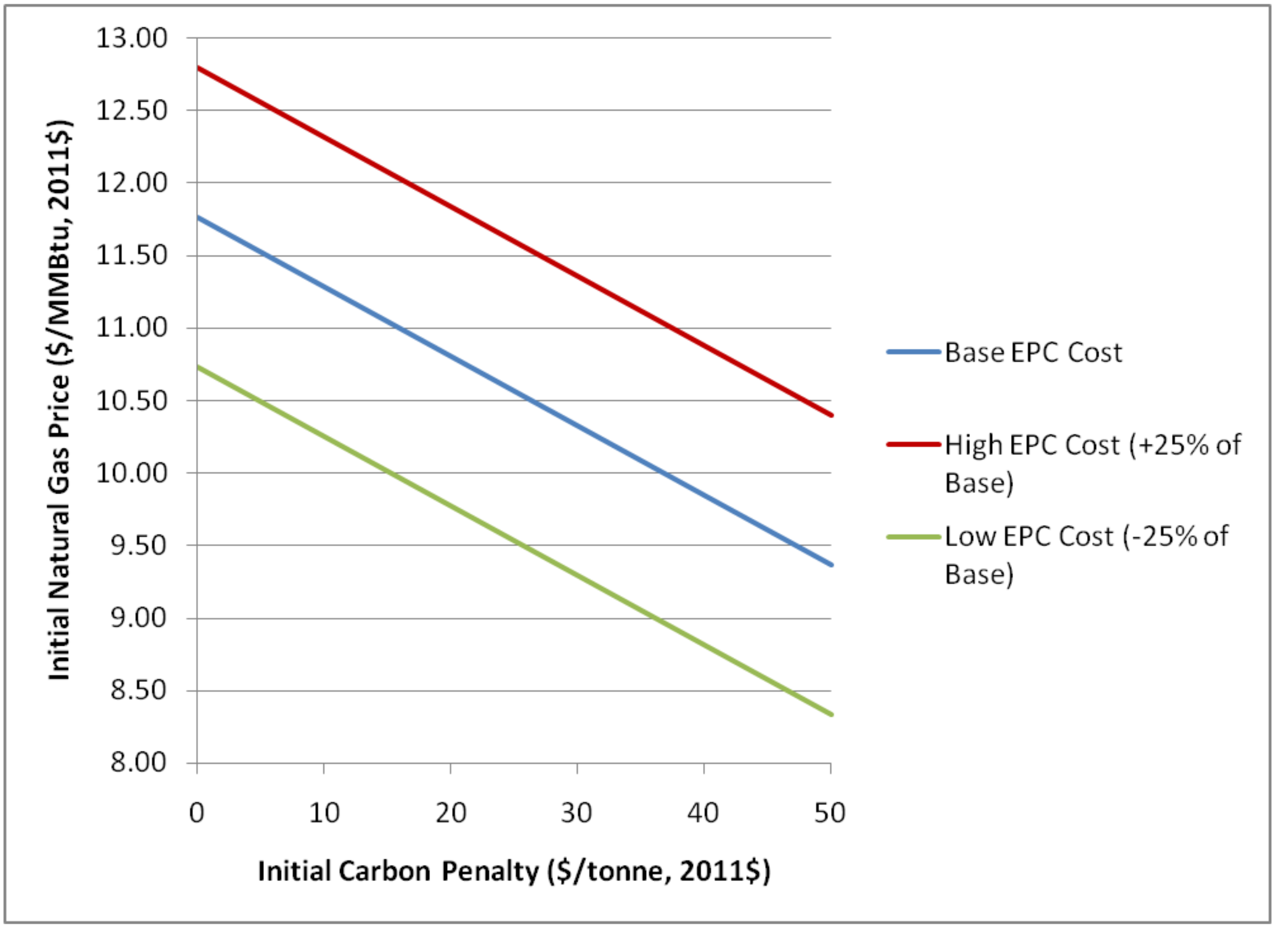
The different breakeven natural gas prices are shown over a range of initial carbon penalties in Figure 4-10. As the carbon penalty increases, the breakeven natural gas price decreases. Without a carbon penalty the breakeven natural gas price is $11.76/MMBtu and with a carbon penalty of $50/tonne CO_2 the breakeven natural gas price decreases to $9.36/MMBtu. During the last five years in the United States natural gas prices peaked at $15/MMBtu and were sustained above $9.50/MMBtu for months at a time; however, current prices are around $4.50/MMBtu and will have to increase significantly in real terms between now and the start of commercial operation and continue to increase during the plant lifetime for the PBR to be more economical than the gas cogeneration plant alternative. The results are also sensitive to variations in power price, which can vary considerably. Lower grid power values reduce the breakeven gas price and vice versa.

Figure 4-10: PBR Breakeven Natural Gas Price for Gas-Fired Cogeneration Plant versus Carbon Penalty



Because the commercial PBR capital costs are also uncertain and have a first order effect of the economic comparison, high and low end PBR capital cost cases are shown in Figure 4-11. As one can see in the figure, a 25% change in PBR capital cost shifts the breakeven natural gas price by ~$1/MMBtu. With a $50/tonne CO_2 penalty and 25% lower EPC costs, the breakeven natural gas price would just over $8/MMBtu.

Figure 4-11: PBR Breakeven Natural Gas Price for Gas-Fired Cogeneration Plant versus Carbon Penalty (PBR EPC Cost Sensitivity)



5.0 PROJECT SCHEDULE

5.1 Introduction

The FOAK PBR Demonstration Plant project schedule establishes a project road map from conceptual design, through construction and startup of the demonstration plant. The schedule identifies various activities and key milestones. Subsequent resource loading of schedule activities provides input for yearly funding profiles starting at the beginning of the design reconciliation tasks in 2012.

In general, the activities presented in the schedule are categorized into project level activities and facility level activities. For consistency with other NGNP-related work, project level activities are identified and grouped in general to be consistent with the Work Breakdown Structure (WBS) provided by Battelle Energy Alliance (BEA)/Idaho National Laboratory (INL). The project schedule integrates the project and facility level activities into a cohesive presentation for the execution of the project.

The schedule of activities for the NSS has been developed with AREVA HTR-Module used as input for scope. The schedules for the ECP and BOP facilities represent conventional scheduling experience.

The length of the schedule is largely driven by the sequence of events required to obtain the COL for the FOAK plant. This reflects guidance provided by the BEA/INL team based on current NGNP pre-application interactions with the NRC. It also reflects experience with licensing associated with other advanced nuclear plant design certification activities.

In general, the schedule activities presented in the schedule are categorized into project level activities and facility level activities. Project level activities include tasks associated with the Owner's Engineer, project design, construction, initial operation and commercial operation of the PBR Demonstration Plant. On the fourth WBS level, project activities are subcategorized within the overall plant and facility level in the following manner:

- Plant Level Design and Integration
- Nuclear Steam Supply Facility (NSS)
- Energy Conversion Plant Facility (ECP)
- Overall Site and Balance of Plant Facility (BOP)

The construction schedule relies on the timely execution of contracts for long lead time equipment to ensure equipment delivery at least 6 months prior to construction installation. Additionally, early site work including clearing, grading, roadways, excavation, underground utilities, batch plants, heavy lift crane, and construction facilities, must be completed prior to the start of construction. All reinforcing and embedded materials for at least the first 6 months of construction must be on site and all prerequisites (contractor mobilization, quality control, training, etc) to allow an immediate start of construction must be completed.

The WBS provides the definition of project activities and brings commonality to the activities described in the schedule and costs included in the FOAK cost estimate. The intent is that the costs included in the estimate may be directly mapped to the schedule using the WBS. It should be noted that the above listed facilities vary somewhat the programmatic WBS to be consistent with the intent of the PBR Status assessment report.

Figure 5-1: PBR Demonstration Project Schedule Summary

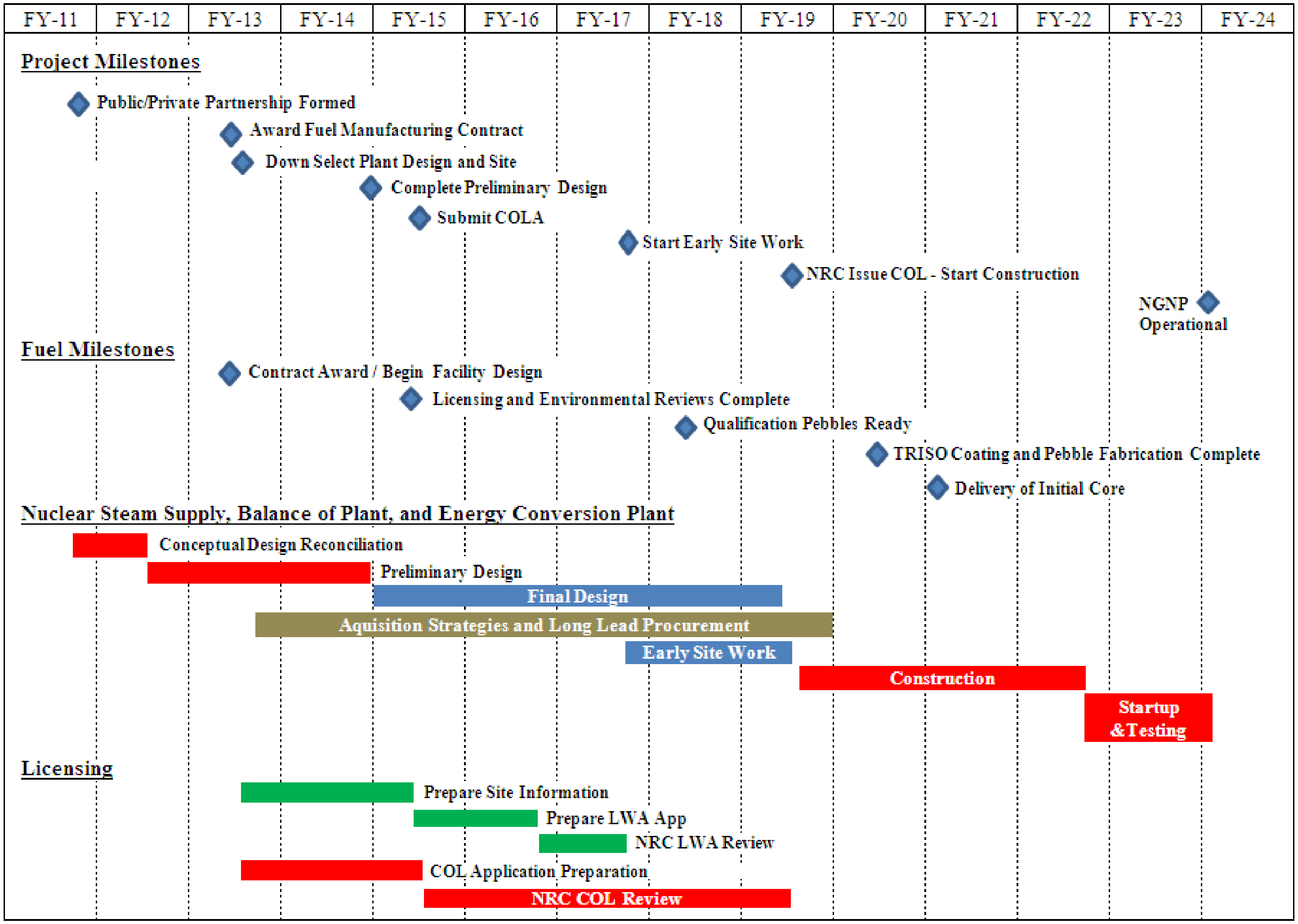


Table 5-1: PBR Assessment Demonstration Project WBS – Top Level

5.2 Schedule Development Approach

The Project Schedule integrates the project and facility level activities into a cohesive presentation for the execution of the Project. This section discusses the underlying rationale for why activities are included and structured as they are in the schedule. The relative importance of some activities with regard to the overall project is also presented, as applicable. All schedule activities are essentially structured using the WBS elements provided.

The schedule of activities for the Nuclear Steam Supply Facility (NSS) has been developed with the project schedule for the HTR-Module schedule used as input and for comparison.

The ECP includes the electricity generation equipment, such as the turbo machinery, condenser, and auxiliary equipment. All well proven technologies that are in extensive deployment today. Therefore, the activities and schedule are developed from related team project experience for similarly sized systems. The schedule for the ECP essentially follows that of the NSS, with the exception of technology development and acquisition strategies. In all other respects, design, construction, commissioning, and startup of the ECP can be achieved concurrently with the NSS schedule.

The schedule approach recognizes the two critical paths through licensing and long lead equipment, which have been scheduled to start during the design phase of the project.

The Regulatory Management Plan will start during the preparation of the initial design criteria. During the development of the Regulatory Management Plan, the project will interface with the regulators to ensure plans and expectations are reflected in the plan and in the project design criteria. The Regulatory Management Plan will cover the COL application, the Environmental Impact Statement and all other permits required to construct and operate the plant. The early preparation of the Regulatory Management Plan will help mitigate risks associated with obtaining licenses and permits in time to support construction, commissioning, and operations.

The procurement, fabrication, and delivery of long lead equipment are also potential schedule risks to the project. The scheduling approach to help mitigate these risks involves early acquisition planning in parallel with specification and drawing preparation. During the development of the Acquisition Strategy, the project manager will involve procurement, quality assurance, engineering, construction, licensing, potential suppliers and the owner’s representatives. The project will benefit from the extensive amount of design work already completed in Germany on the HTR-Module. This will allow the preparation of specifications and drawings required for the bid process to be developed in parallel with acquisition planning. The resolution of any technology, code or regulatory risks will be captured in the Acquisition Strategies and will be managed in the project risk management system. Funding requirements for each Long Lead Acquisition will be coordinated and concurred with the Owner’s Representative before the Acquisition Strategy is approved by the project. The scheduled delivery of Long Lead equipment will be planned to occur at least 6 months prior to installation. The strategy will capture transportation and storage requirements at the construction site.

The construction schedule for the facility relies on early site preparation to start in October 2017, coincident with the Owners decision to construct. The early site preparation includes site clearing, grading, excavation, underground utilities, batch plants, a tower crane, construction trailers, rebar and embedment delivery, and civil contractor mobilization. The Regulatory Management Plan will include the Limited Work Authorization and Environmental Impact Statement required for early site preparation activities. Completion of these activities coupled with the delivery of Long Lead Equipment will permit construction of the buildings to begin immediately after receipt of the COL from the NRC.

The resulting schedule activities have been organized to conform to the WBS developed for this assessment project, as much as practicable.

5.3 Schedule Bases and Assumptions

The schedule bases require the formation of a Public-Private Partnership in September 2011. This Partnership will fund the design and licensing prerequisites for construction of the plant. Additionally, the acquisition strategy for each piece of long lead equipment will most likely require material procurement and fabrication long before a final decision to construct (October 2017) is made. To meet the construction schedule, it is assumed that the Partnership will fund the fabrication of long lead equipment in advance of making the final decision to construct.

Early site work requires the issuance of the LWA and an EIS in addition to the partnership's decision to proceed with construction of the plant. These three approvals are assumed to be in place to support the start of early site work on October 2017. The completion of early site work activities, including mobilization of the civil-structural contractor is needed to permit construction to proceed as soon as the COL is issued by the NRC and the Partnership authorization to proceed is given.

The fabrication and delivery of long lead equipment, such as the reactor pressure vessel will require detailed planning and coordination with perspective fabricators and their suppliers. Any outstanding technology or code compliance issues will be factored into the acquisition planning. It is assumed that technology and code compliance issues will not restrain fabrication and delivery of this equipment. The unique safety related materials will likely require a special mill run in addition to coordination with the NRC in advance of a COL submission. If the fabricator does not possess an approved Nuclear Quality Assurance program (10 CFR 50, Appendix B), special measures will be necessary ensure compliance with the QA Program.

Depending on the site location, the transportation of equipment to the site may also require additional contracts and equipment. Sub-assembly fabrication on site will be factored into the constructability evaluation and planning process. For this reason, the schedule shows the Acquisition Planning for these long lead pieces of equipment starting as early as practical to minimize any possibility of late delivery.

The current construction schedule assumes that modular construction is factored into the design. During conceptual and preliminary design we will conduct modular construction studies factoring in our current experience. The results of these modular construction may require heavy lift capability be installed during early site preparation.

It is assumed that demobilization will occur during cold startup testing and that hot startup and commissioning can be finished in one year. To help achieve this one year schedule we will maximize assembly and testing in the shop. The planning for startup testing and commissioning will start during the conceptual and preliminary design phase and will continue up through cold startup.

5.3.1 Engineering/Design

The Project Level Design element includes conceptual design, preliminary design, final design, and acquisition strategies project level sub elements. Each of these elements includes Plant Level Design & Integration, overall plant and facility engineering, and design activities levels.

For the purposes of the schedule, Plant Level Design & Integration, Site and BOP engineering, and ECP and NSS design efforts will occur concurrently, and will support the licensing application process through preliminary design.

Anticipated required development activities for each of the facilities, as well as the basis for related design activities, are described further in the sub-sections below.

Design activities for the HTR-Module will begin with a design reconciliation activity, which includes the adaptation of the German HTR-Module design to U.S. standards and regulatory requirements. The reconciliation activity will produce design criteria that meet U.S. codes, standards, and regulatory requirements. These design criteria documents, along with the German HTR-Module design data, will support conceptual and preliminary design development as well as the COL application.

5.3.1.1 Conceptual, Preliminary, and Final Design

Engineering and design work, including plant level design and integration, will occur over three project level elements of conceptual, preliminary, and final design. During the conceptual and preliminary design periods, the facility design efforts will support the plant level safety analyses, and ultimately the NRC licensing application. In order to effectively support the licensing application, a design freeze occurs at the end of the preliminary design. This design freeze enables the completion of the final safety analysis and integrated safety analysis summary.

It is anticipated that the conceptual design can be somewhat shorter than usual for similar projects. This is because the HTR-Module design has been previously advanced through the end of the preliminary phase in order to support preparation for the SAR for presentation to German regulators. A period of 9 months is allowed in the schedule to revisit the conceptual design and reconcile design criteria to meet the NGNP mission requirements and conform to U.S. codes, standards, and regulations.

Engineering and design activities are based on the experience from past projects and similar facilities. For the most part, the design schedules for the NSS, ECP and BOP occur concurrently.

5.3.2 Acquisition Strategies

The acquisition strategies work element includes activities such as the development of long lead item procurement strategies, material and equipment procurement, the manufacturing of long lead items, and transportation of these items to the project site. The underlying assumption of this portion of the schedule is that an integrated vendor team will design, procure, and build the facility.

A second aspect of acquisition strategies is the development, bid, and award of contracts for the construction of the facilities.

Table 5-2: Long Lead Procurement Items by NGNP Facility

Facility	Long Lead Procurement Item
NSS	Fuel Pressure Vessels Helium Pressure Boundary Core Barrel Assemblies Hot Gas Ducts Core Structure Ceramics (Graphite) Steam Generators Tube Bundles Fuel Handling & Storage Systems Helium Services System
ECP	Turbo Machinery Feed Water Heaters Condensate Feed-water Pumps Condenser De-aerator Cooling Towers
BOP	Training Simulator

5.3.3 Licensing and Permitting to Construct the NGNP Facility

5.3.3.1 NRC Licensing

During conceptual and preliminary design we will establish design criteria for the project, which will establish codes, standards, and methods to be used in producing the design of the NGNP facility. We will meet with the NRC shortly after mobilization to establish specific regulatory requirements and to identify regulatory changes needed for the NRC to review the COL application. Typically, the NRC's Standard Review Plan is used to guide the organization and content of the COL. For the NGNP it is possible that special guidance will be provided. Design criteria and our licensing commitments will be closely linked. The flow down of design criteria into design products will help ensure compliance with licensing commitments.

5.3.3.2 Environmental Permitting

The state and local permitting process will occur in one phase for permitting of the NSS and the balance of the NGNP facility.

5.3.4 Construction Activities

5.3.4.1 License and Permitting to Operate

During the course of construction activities, the NRC will be inspecting the work. This activity is shown under the License and Permitting to Operate WBS element.

5.3.4.2 Overall Site and BOP Construction

Construction activities are organized as follows:

- Site preparation & foundations
- Buildings and balance of plant
- Process piping, equipment installation, and mechanical construction
    - Auxiliaries
    - Pipelines & interconnections
- Substation & power distribution
- Instrumentation and controls installation

Construction times for the above include engineering and procurement of equipment and materials not identified as long lead procurement items. These times also allow for approximately two months per year of lost construction time due to extreme cold weather conditions during the winter. Demobilization will begin prior the completion of the electrical and I&C systems and is assumed to end six months after completion of the construction activities.

5.3.4.3 Nuclear Steam Supply Facility Construction

Construction activities are organized as follows:

- Civil – civil site work and buildings within the NSS facility
- Process piping, equipment installation and mechanical construction
    - NI Auxiliary systems
    - Reactor and Steam Generator systems
    - Main support systems
    - Special tools and Equipment Handling Systems
    - Initial fills, spares, and consumables

- Electrical installation
- Instrumentation and controls installation
- Demobilization

Construction times for the above include engineering and procurement of equipment and materials not identified as long lead procurement items.

5.3.4.4 Energy Conversion Plant Construction

Construction activities are organized as follows:

- Site development
- Buildings and structures
- Process piping, equipment installation and mechanical construction
    - Steam turbine generator vendor package
    - ECP auxiliaries
    - Cooling system
- Electrical installation
- Instrumentation and controls installation
- Initial fills, spares & consumables

Construction times for the above include procurement of equipment and materials not identified as long lead procurement items.

5.3.5 Training

The NSS operator training is anticipated to begin prior to the start of construction and be completed during the pre-commissioning testing. Completion of the training will be marked by the operators successfully passing the NRC licensing test. The NSS training simulator will be installed and operational in time to support completion of certification training. Certification training is assumed to encompass aspects of the NSS, ECP and BOP.

5.3.6 Initial Operation

Pre-commissioning, commissioning, and startup activities for the PBR Demonstration Plant include both preoperational testing during construction as well as startup activities after construction completion:

1) Pre-commissioning activities prior to completion of construction and nuclear fuel loading
2) Startup & testing activities that occur after completion of construction and fuel loading

Pre-commissioning entails such tasks as verification of the proper installation of piping, mechanical equipment, flushing of piping, and hydrostatic testing of tanks and vessels. Startup and testing entails a more formal certification by project engineering staff of equipment operation and conformance to design specifications. In addition, NSS commissioning activities include fuel loading, low power testing, synchronization to the grid, power ascension testing, and plant acceptance testing. These activities demonstrate startup testing procedures and initial operation capability and, thereby, establish precedents for the commercial plant.

5.3.7 Commercial Operation

The FOAK schedule includes a commercial operation period. At the end of this period, the facility will be shut down for inspections of the various facilities to determine the condition of equipment material components. This period will also afford to opportunity to perform routine equipment maintenance.

5.4 Schedule Analysis and Critical Path

The critical path for this schedule runs through Concept Design Reconciliation, Preliminary Design, Integrated Safety Analysis, COL Application submittal, NRC review and issue of the COL. Critical path continues with construction, startup, and initial operation of the plant. Critical path activities are highlighted in red on Figure 5-2.

The primary driver for this critical path is associated with receiving a COL from the NRC. The preparation of the application requires site selection and advanced completion of the preliminary design. The COL Application process will be preceded by a Regulatory Management Plan and joint planning with the NRC. Although this preceding activity is not critical path, it is necessary to support preparation of a compliant application in 2 years.

Upon receipt of the COL from the NRC, it assumed that Nuclear Quality Level Construction will commence. Construction and Startup Testing is scheduled to take place over a 5 year period. The successful completion of these activities during this period is dependent on completion of significant Early Site Work activities, long lead equipment deliveries, modular construction and shop testing.

Other potential critical paths could result if any delays occur in the following:

- Fuel Fabrication and Qualification
- Long Lead Item Acquisition
- Early Site Permit Submittal and Review

Fuel Fabrication and Qualification

Fuel fabrication, qualification, and delivery are required to support Hot Startup testing. At this stage of planning, delivery supports Hot Testing with about 1 year of float. Any significant delays in this element of the program could put Fuel Fabrication and Qualification on the critical path.

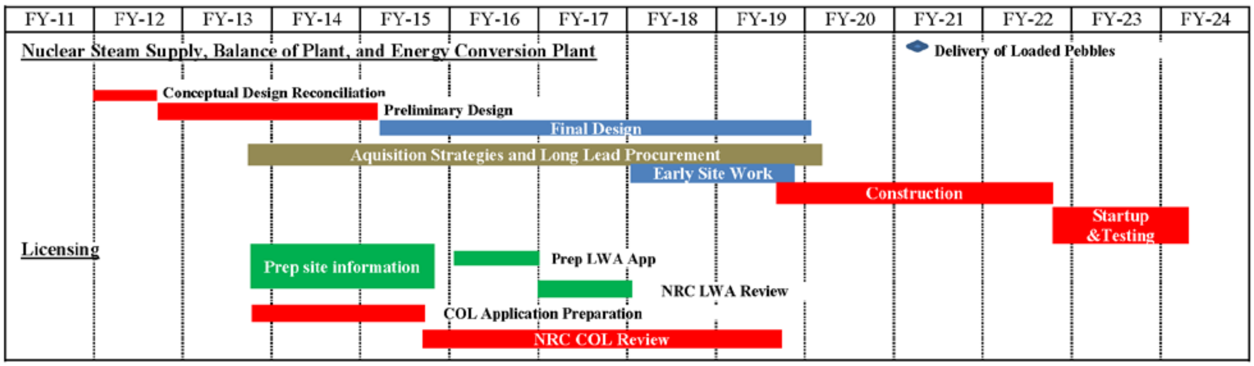
Long Lead Item Acquisition

The acquisition, fabrication, and delivery of FOAK long lead items have the potential of becoming critical path activities. Acquisition strategies, specifications, and contract awards will factor in appropriate margins to account for these schedule risks. The acquisition of long lead equipment will also require funding well in advance of the start of construction. The timely delivery of long lead items to support field installation, are potential critical path items. These long lead deliveries will be monitored in the project risk management program.

Limited Work Authorization Application Submittal and Review

The LWA application submittal and review supports the commencement of early site construction work. A substantial amount of non nuclear construction is necessary to permit nuclear construction to start shortly after the COL is issued by the NRC. Early site work includes grading, roadways, yard drainage, barge facility, batch plants, construction facilities, underground utilities, excavation, contracting, receipt of embedded commodities, and non nuclear quality construction activities. The preparation of the Limited Work Authorization application require site selection and site exploration data along with preliminary design data. The permitting process includes public hearings and an ACRS review. The schedule has allowed two years for gathering site information and 15 months for preparation of the LWA application and another 12 to 15 months for the NRC review process. The LWA schedule has very little schedule float and could become a critical path driver if any of the associated activities are delayed.

Figure 5-2: PBR Demonstration Project Critical Path



6.0 GENERAL ASSUMPTIONS

The basis, scope, and approach to cost and schedule development are describe in previous sections of this report. A list of additional assumptions that apply to both cost and schedule are included below.

- Sufficient funding is available to allow a full fuel qualification program
- Required test reactors are available
- Overall fuel performance during irradiation and safety testing is successful
- Fuel coating challenges are not encountered
- Test facilities such as helium loops for components qualification are available within schedule requirements
- Suppliers of graphite with low impurity content are available and can deliver on schedule.
- Bounding requirements for defining the reference configuration for the FOAK design can be determined for site issues related to ground conditions or the industrial environment.
- Helium production may is available to reasonably satisfy the needs of a HTR fleet over a significant period of time (the needs for HTR should not exceed a few percent of the He production capacities over a period of roughly one century).
- Sufficient funding is available to sustain a fully competent project staff with progressively stable groups of specialists that are used for performing the design work for NGNP FOAK projects.

7.0 RISK ITEMS

The overall technical risks are discussed to some extent in the technology readiness portions of this assessment project. These risks appear to be moderate. However, the overall schedule risk is judged to be significant due to external programmatic factors. These risks should be manageable, if prompt action is taken in key areas.

Specific key risks to project success are listed below.

Control of overall NGNP project risk requires prompt project execution, the development of a technology roadmap with off-ramps for key technology risks, a strategy to avoid funding and resource constraints, and alignment with commercial market needs. Adequate steps exist to reduce or mitigate the project risk.

Most of these risks would be applicable to other NGNP designs as well. This is not a complete or comprehensive risk analysis, but is rather a compilation of known or obvious risks for a FOAK NGNP HTR project, with consideration of the limited scope of this PBR Technology Assessment effort. A comprehensive risk identification and management program should be employed as the project moves forward. Some risk items below include discussion of possible mitigation strategies.

Four areas appear to present the greatest risk to the NGNP project. The following are the "key" risk areas:

- Fuel Development and Performance
- Heavy Component Procurement and Fabrication
- Licensing

Each is discussed in Table 7-3 along with other risks:

Table 7-3: Summary of Project Risks

Risk Item Description
Fuel Development and Performance
The fuel development, qualification, and fabrication activities comprise the project's critical path and there is not sufficient contingency to accommodate any setbacks in the process. Should any of the fuel irradiations produce bad results, it will be difficult to maintain a schedule that meets the 2023 startup target.
Failures or delays in the fuel qualification program would likely result in increased cost of fuel development, overall project schedule delays and increase costs associated with schedule delays.
In the case of fuel performance, the probability of the risk can be reduced, but the potential consequence cannot be significantly minimized. Collective mitigation strategies include: • Initiate and fully fund the fuel development and qualification effort in the near future. • Identify fuel irradiation and inspection needs immediately and reserve required resources. • Fuels team is set up to consider a wide range of fuel variables that should result in an acceptable qualification effort. • Develop fuel fabrication process based on the use of multiple, proven coaters. There is no clear fallback position with regards fuel performance that is palatable with respect to schedule or redeeming with respect to plant economics. It is possible that the NGNP design or operating strategy could be adjusted such that much less demand is placed on the fuel resulting in a more favorable or acceptable operating regime relative to fuel performance. However, this implicitly assumes that a minimum level of acceptable fuel performance commensurate with past German fuel experience can be obtained.
Equipment Supply Chain and Heavy Component Procurement and Fabrication
Final component size and configuration may require adjustment based on design reconciliation to meet U.S. requirements, preliminary design results, and licensing review results. This could affect overall plant cost or engineering cost. Factors that could impact design include but are not limited to: • Maintenance space requirements; • final vendor component specifications; • adjustments for site conditions or external hazards specific to selected plant location, and; • Accident analysis results from preliminary design.

If the sizes of the main components are exceeding certain limits, there might be no manufacturer or only a single one having the needed manufacturing capability.
If the sizes of the main components are exceeding certain limits, there might be big difficulties or it might even be impossible to transport them to the envisioned sites.
With respect to procurement and fabrication of large forgings for the reactor vessel, industrial capacity is limited in forging size and experience such that the delivery timeframe of the forgings may not be compatible with the NGNP schedule. For other, more standard large components (e.g., steam turbines), feasibility is not an issue but timely procurement is because of the lengthy procurement lead times (4-5 years) arising from the world-wide demand for these components. To mitigate these risks, the following actions can be taken: • Book large forgings and casting material as early as possible. Engage the potential primary supplier for forgings early in the conceptual design process assess feasibility and schedule issues. • Ensure commitments for the procurement of standard large components are placed on a schedule compatible with NGNP startup.
The risk of escalation of the total capital cost of the FOAK project exists. The cost estimate presented in this report does not include individual vendor pricing of major components. Vendor interaction and selection to better understand these costs should be pursued early in the project to mitigate this risk.
Licensing
There are risks of schedule delays and increased licensing costs if NRC does not accept FOAK NGNP designs such as the HTR-Module. Other impacts of this risk include possible need to re-design portions of the plant, resulting in additional engineering cost and potential construction or material cost impacts.
The impacts of evolving regulation regarding NGNP technology could result in design, cost, or schedule impacts.
Final validation of the safety case for the NGNP has not been completed. Without superior fuel performance, the safety case is jeopardized and the licensing strategy becomes void. The implication is a costlier plant due to the requirement for a containment and/or an emergency planning zone that expands well beyond the site boundary, necessitating complicated and costly emergency planning measures. This affects locating the commercial plant near population centers.
The NRC may find the radionuclide containment approach unacceptable. This risk is also tied to fuel performance goals. Mitigation strategies here include: • Close interaction with the NRC on this issue. • Ensure fuel performance goals are met so that a hard containment is unnecessary.
Waste Disposal
There are uncertainties regarding the cost of storage disposal of spent fuel from a PBR.
There are uncertainties regarding the long term solution to the graphite disposal. The ability to manage unloaded graphite as low level waste could impact overall cost, environmental impact, and general acceptance of the technology.

Other Risks
Construction and large component transportation cost can be impacted by site selection. The cost impact of extensive earth work or location not near a deep water port or rail need to be assessed during site selection.
The effort for engineering and design of the FOAK project could increase significantly if significant changes are required based on results of engineering or safety analysis, adjustments of the HTR-Module design to U.S. code and regulatory requirements, or changes to the design due to customer request. Such an increase in engineering effort will be realized in both cost increases and schedule delays.

8.0 OPPORTUNITIES FOR COST REDUCTION

The estimated costs for the HTR-Module do not reflect potential cost reductions that could be achieved with modernized construction techniques. Opportunities to reduce overall cost exist and should be evaluated in future stages of the project. Some of these opportunities include the following:

- Reduction of concrete in the nuclear island structures.
- Reduction of construction costs through modularization. This would require some rearrangement of the design to facilitate construction sequence associated with modularization approach.
- Reductions in staffing levels.
- Consolidation of support systems and facilities for multi-plant sites. This could include:
    - New and spent fuel handling systems
    - Central Gas Storage Systems.
    - Radwaste Systems
    - Consolidation of control rooms and interface cabinet areas
- Increase reactor design power to 250 MW_t.
- Increase number of reactors per building/module.

This project effort did not include further assessment of the likely cost impact or feasibility of these or other cost reduction opportunities.

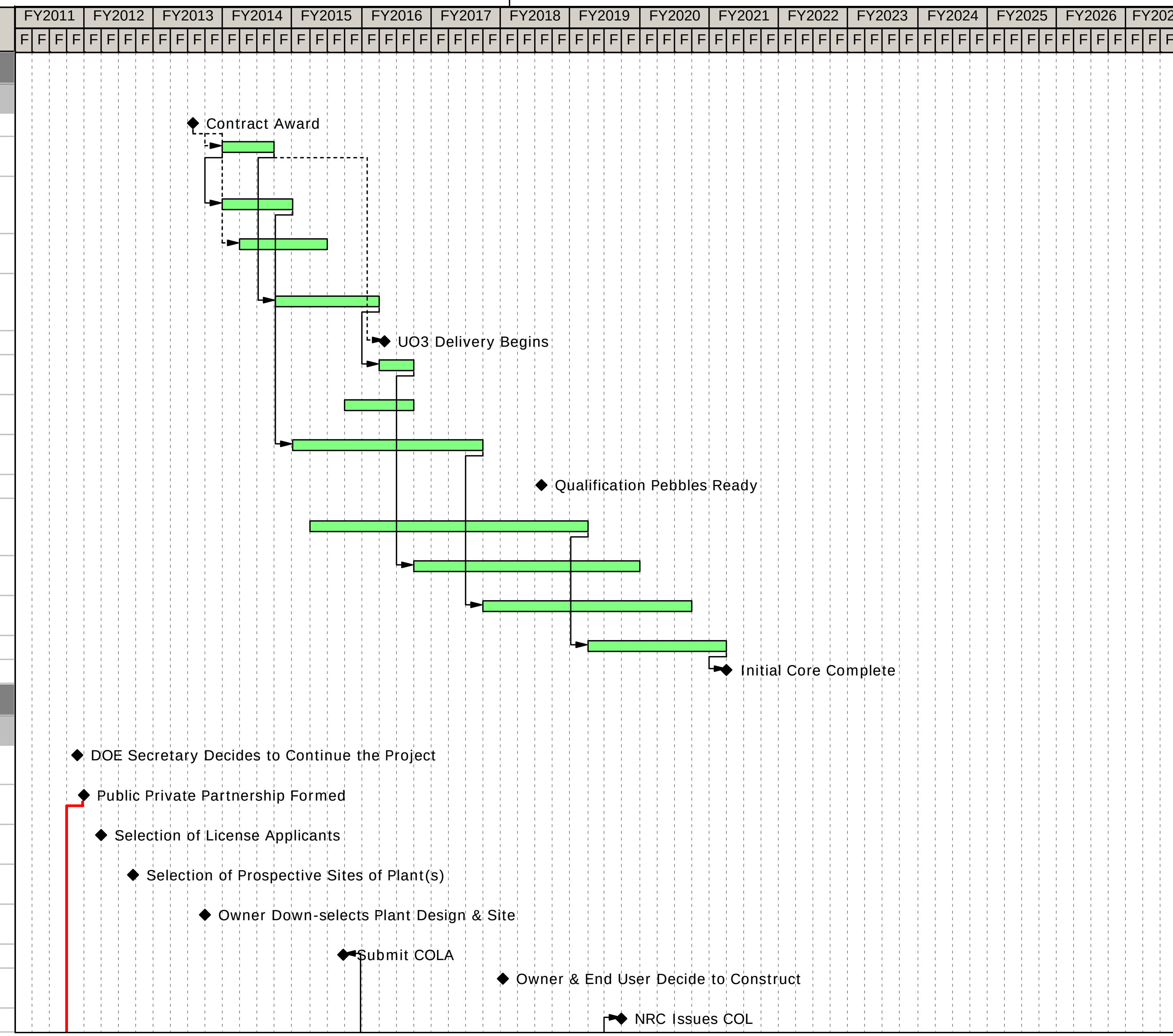
9.0 REFERENCES

1. AREVA NP, Inc, 12-9149697-000, Pebble Bed Reactor Plant Design Description, 1/31/2011
2. DOE-GT-MHR-100002, Evaluation of the Gas Turbine Modular Helium Reactor, February 1994
3. INL/EXT-07-12107 Rev. 1, Advanced Fuel Cycle Cost Basis, March 2008
4. INL/MIS-08-151113 Draft G, NGNP Program Planning Bases for the Schedule and Cost Estimates, 11/11/2010
5. INL/EXT-07-12441 Rev. 2, Updated NGNP Fuel Acquisition Strategy, December 2010
6. INL, Project Briefing for Nuclear Energy Advisory Committee Presentation, September 2010
7. Babcock and Wilcox, BWED-10-151 Revision 00, Manufacturing Cost and Schedule Estimate in support of Modular Pebble Bed Reactor Technology Assessment, 11/16/10
8. NGNP Industry Alliance white paper – NGNP Project Implementation Strategy, November 2009

APPENDIX A: DEMONSTRATION PLANT SCHEDULE

28-Jan-11 10:24

Activity ID	Activity Name	Original Duration	Start	Finish	Predecessors
FUEL MANUFACTURING		2003	01-May-13	01-Jan-21	
PLANT 1 - FACILITY STARTUP & INIT...		2003	01-May-13	01-Jan-21	
FUEL-1000	Contract Award	0	01-May-13*		
FUEL-1010	Kernel Fabrication Upgrade Design	196	01-Oct-13*	01-Jul-14	FUEL-1000
FUEL-1070	Pebble Compact Equipment and Facility Upgrades Design	262	01-Oct-13	01-Oct-14	FUEL-1010
FUEL-1020	Licensing and Environmental Reviews	326	01-Jan-14*	01-Apr-15	FUEL-1000
FUEL-1030	Equipment Procurement and Installation for Kernel Fabrication	393	02-Jul-14	01-Jan-16	FUEL-1010
FUEL-1050	UO3 Delivery Begins	0		01-Feb-16*	FUEL-1010
FUEL-1040	Shakedown for Kernel Fabrication	130	04-Jan-16	01-Jul-16	FUEL-1030
FUEL-1080	Equipment Removal and Over-Build of 15A	263	01-Jul-15*	01-Jul-16	
FUEL-1090	Equipment Procurement, Installation and Shakedown	717	02-Oct-14	30-Jun-17	FUEL-1070
FUEL-1110	Qualification Pebbles Ready	0	01-May-18*		
FUEL-1120	Design, License and Fabricate Shipping Containers	1044	01-Jan-15*	01-Jan-19	
FUEL-1060	Kernel Fabrication & Delivery to NOG1	847	04-Jul-16	01-Oct-19	FUEL-1040
FUEL-1100	TRISO Coating and Pebble Fabrication	783	03-Jul-17	01-Jul-20	FUEL-1090
FUEL-1130	Delivery of Loaded Pebbles	523	02-Jan-19	01-Jan-21	FUEL-1120
FUEL-1140	Initial Core Complete	0		01-Jan-21	FUEL-1130
NGNP		3218	31-Aug-11	29-Dec-23	
DOE MILESTONES		3218	31-Aug-11	29-Dec-23	
ENGD-1655	DOE Secretary Decides to Continue the Project	0		31-Aug-11*	
ENGD-1665	Public Private Partnership Formed	0		30-Sep-11*	
ENGD-1675	Selection of License Applicants	0		02-Jan-12*	
ENGD-1685	Selection of Prospective Sites of Plant(s)	0		15-Jun-12*	
ENGD-1695	Owner Down-selects Plant Design & Site	0		01-Jul-13*	
ENGD-1870	Submit COLA	0		30-Jun-15	ELIC-1050
ENGD-1715	Owner & End User Decide to Construct	0		13-Oct-17*	
ENGD-1795	NRC Issues COL	0		28-Jun-19	ELIC-1379



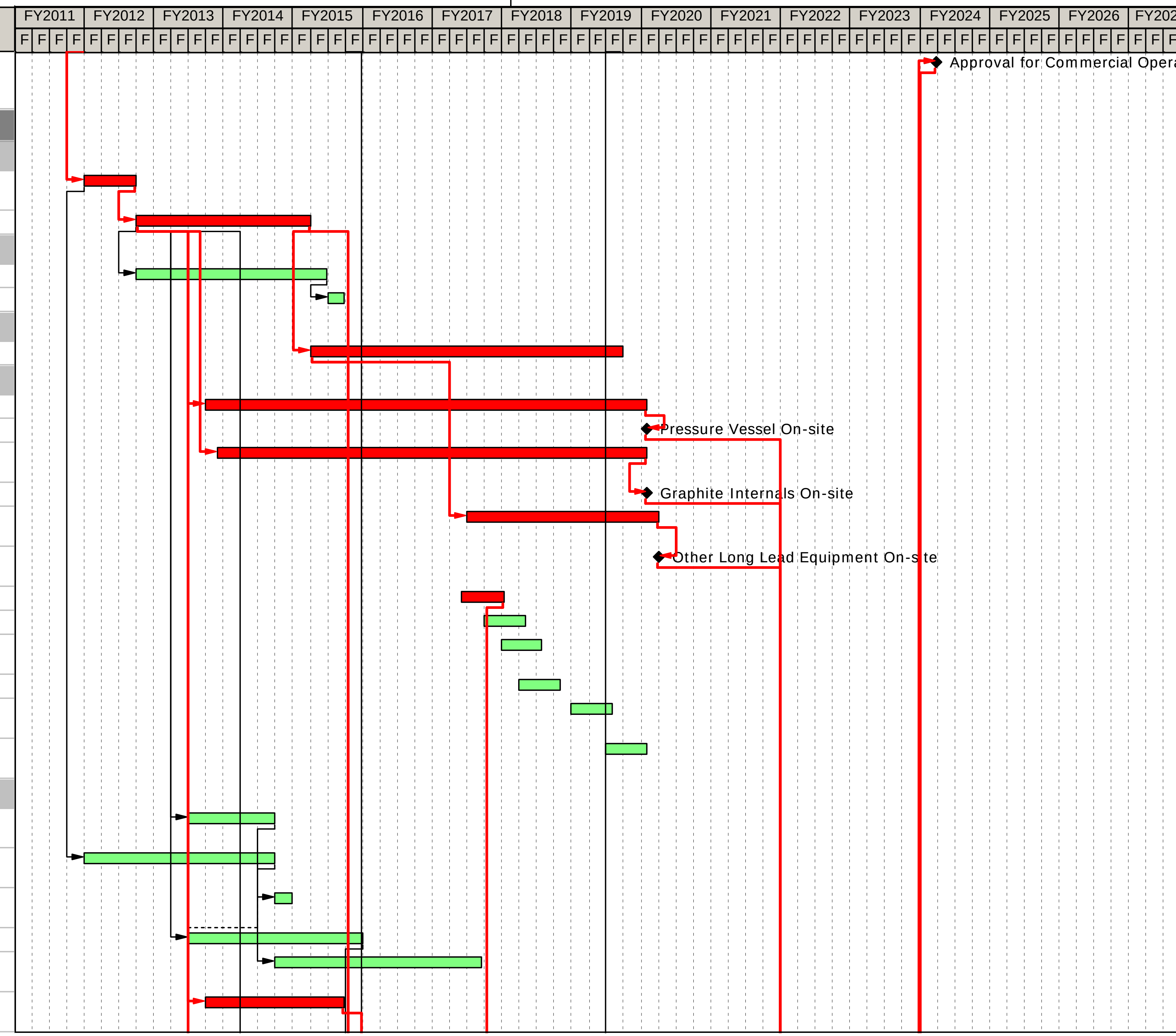
Actual Work | Critical Remaining Work | Remaining Work | Milestone

Page 1 of 5

TASK filter: All Activities

28-Jan-11 10:24

Activity ID	Activity Name	Original Duration	Start	Finish	Predecessors
IOPR-1250	Approval for Commercial Operation	0		29-Dec-23	ELIC-1440, CLIC-1020, IOPR-1200
2 00 000 ENGINEERING/DESIGN		3194	03-Oct-11	28-Dec-23	
2 32 000 - RECONCILE DESIGN CRIT...		848	03-Oct-11	31-Dec-14	
ENGD-1610	Reconcile Design Criteria for US Reg't	195	03-Oct-11	29-Jun-12	ENGD-1665
ENGD-1600	Preliminary Design	653	02-Jul-12	31-Dec-14	ENGD-1610
SAFETY ANALYSIS		782	02-Jul-12	30-Jun-15	
ENGD-1740	Final Safety Analysis	717	02-Jul-12	31-Mar-15	ENGD-1600
ENGD-1750	Prepare ISA Summary	65	01-Apr-15	30-Jun-15	ENGD-1740
2 34 000 - FINAL DESIGN		1172	01-Jan-15	28-Jun-19	
ENGD-1830	Final Design	1172	01-Jan-15	28-Jun-19	ENGD-1600
ACQUISITION STRATEGIES & LONG ...		1697	01-Jul-13	31-Dec-19	
EACQ-1024	Vessels Acquisition	1652	01-Jul-13	29-Oct-19	ENGD-1600
EACQ-1035	Pressure Vessel On-site	0		29-Oct-19	EACQ-1024
EACQ-1124	Graphite Internals Acquisition	1607	02-Sep-13	29-Oct-19	ENGD-1600
EACQ-1175	Graphite Internals On-site	0		29-Oct-19	EACQ-1124
EACQ-1840	Other Long Lead Acquisitions	717	03-Apr-17	31-Dec-19	ENGD-1830
EACQ-1850	Other Long Lead Equipment On-site	0		31-Dec-19	EACQ-1840
EACQ-1830	Civil Contract (Site Work)	163	01-Mar-17*	13-Oct-17	
EACQ-1790	Structural Contract	153	03-Jul-17*	31-Jan-18	
EACQ-1890	Buildings & Balance of Plant Contract	151	02-Oct-17*	30-Apr-18	
EACQ-1810	Electrical Contract	152	01-Jan-18*	31-Jul-18	
EACQ-1800	Process Piping, Equipment, Mechanical Contract	152	01-Oct-18*	30-Apr-19	
EACQ-1820	Instrumentation & Control Contract	154	01-Apr-19*	31-Oct-19	
2 41 000 - LICENSING & PERMITTING ...		3194	03-Oct-11	28-Dec-23	
ELIC-1022	Regulatory Management Plan Preparation / Issue	325	01-Apr-13	27-Jun-14	ENGD-1600
ELIC-1120	Topical Reports Methodology	715	03-Oct-11	27-Jun-14	ENGD-1610
ELIC-1070	Site Geotechnical Investigation	64	30-Jun-14	25-Sep-14	ELIC-1080, ELIC-1022
ELIC-1080	Environmental Analysis	653	01-Apr-13	30-Sep-15	ENGD-1600
ELIC-1160	NRC Review of Topical Reports	775	30-Jun-14	16-Jun-17	ELIC-1120
ELIC-1100	Prepare Site Information	522	01-Jul-13	30-Jun-15	ENGD-1600



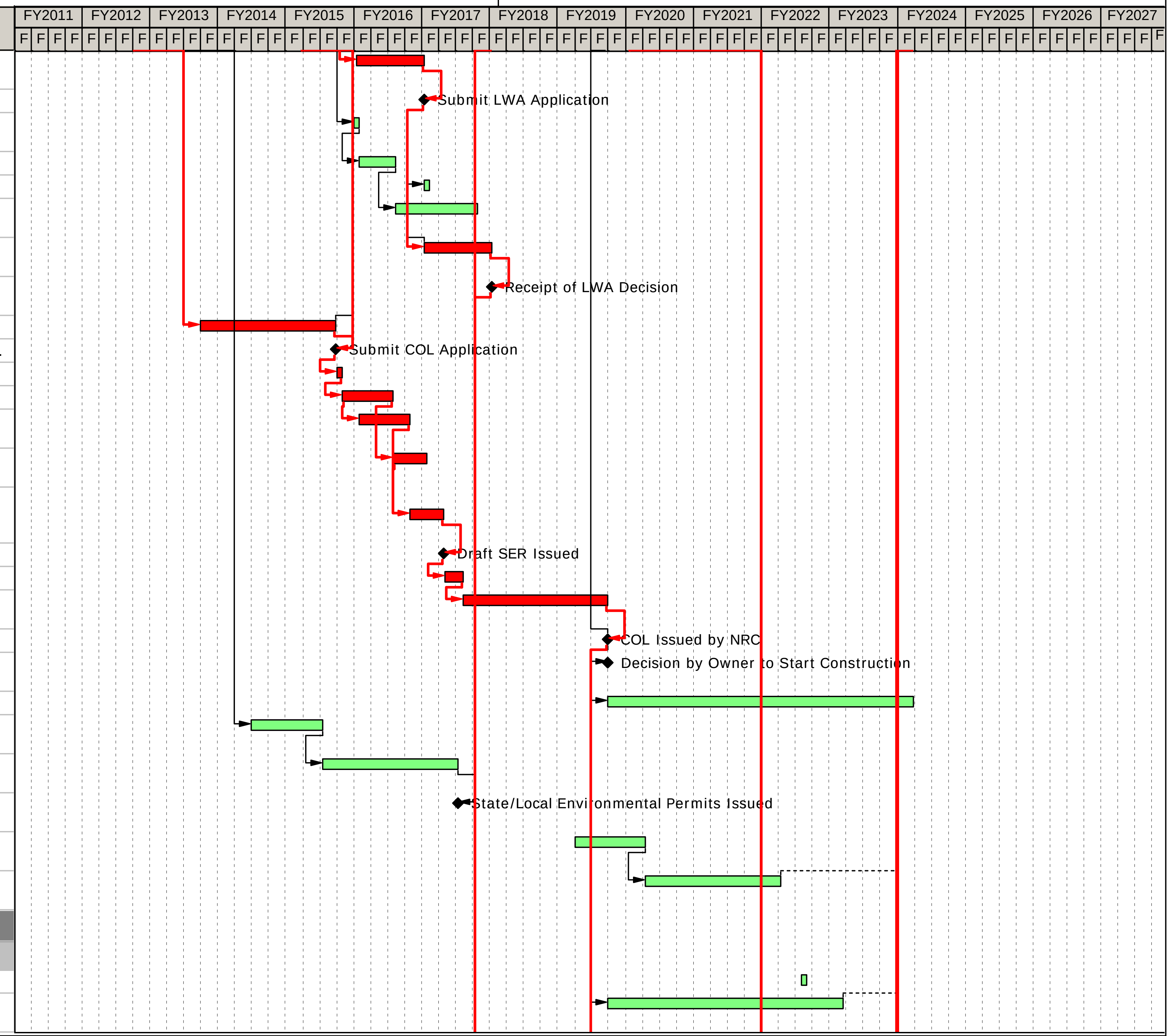
Actual Work
Critical Remaining Work
Remaining Work
Milestone

Page 2 of 5

TASK filter: All Activities

28-Jan-11 10:24

Activity ID	Activity Name	Original Duration	Start	Finish	Predecessors
ELIC-1090	Prepare LWA Application	261	15-Oct-15	13-Oct-16	ENGD-1600, ENGD-1830
ELIC-1095	Submit LWA Application	0		13-Oct-16	ELIC-1090
ELIC-1170	Notice of Intent to Prepare EIS	22	01-Oct-15	30-Oct-15	ELIC-1080
ELIC-1180	Draft EIS	140	02-Nov-15	13-May-16	ELIC-1170
ELIC-1130	Docketing Review	21	13-Oct-16	10-Nov-16	ELIC-1110
ELIC-1190	Final EIS	314	16-May-16	27-Jul-17	ELIC-1180
ELIC-1110	NRC Review of LWA Application	262	13-Oct-16	13-Oct-17	ELIC-1095
ELIC-1220	Receipt of LWA Decision	0		13-Oct-17	ELIC-1110
ELIC-1050	Preparation COL Application	522	01-Jul-13	30-Jun-15	ENGD-1600
ELIC-1055	Submit COL Application	0		30-Jun-15	ELIC-1050, ...
ELIC-1270	Docketing Review	22	01-Jul-15	30-Jul-15	ELIC-1055
ELIC-1280	NRC Review, Develop RAI's	196	31-Jul-15	29-Apr-16	ELIC-1270
ELIC-1300	NGNP Project Response Period for 1st round of RAI's	196	30-Oct-15	29-Jul-16	ELIC-1280
ELIC-1310	NRC Issues 2nd Round of RAI's	131	02-May-16	31-Oct-16	ELIC-1280
ELIC-1320	NGNP Project Response Period for 2nd round of RAI's	132	29-Jul-16	30-Jan-17	ELIC-1310, ELIC-1300
ELIC-1330	Draft SER Issued	0		30-Jan-17	ELIC-1320
ELIC-1350	NRC Prepares Final SER	74	31-Jan-17	12-May-17	ELIC-1330
ELIC-1150	NRC & Staff Reviews and Hearings	555	15-May-17	28-Jun-19	ELIC-1350
ELIC-1379	COL Issued by NRC	0		28-Jun-19	ELIC-1150
ELIC-1389	Decision by Owner to Start Construction	0	01-Jul-19		ELIC-1379
ELIC-1230	ITAAC Resolutions	1174	01-Jul-19	28-Dec-23	ELIC-1379
ELIC-1400	Prepare State/Local Agency Permits	272	01-Apr-14	15-Apr-15	ENGD-1600
ELIC-1410	State/Local Agency Review of Permits	521	16-Apr-15	13-Apr-17	ELIC-1400
ELIC-1415	State/Local Environmental Permits Issued	0		13-Apr-17	ELIC-1410
ELIC-1430	Prepare State/Local Permits for Operation	270	01-Jan-19*	13-Jan-20	
ELIC-1440	State/Local Agency Review Permits for Operation	524	14-Jan-20	14-Jan-22	ELIC-1430
3 00 000 - CONSTRUCTION		1349	16-Oct-17	15-Dec-22	
3 42 000 - LICENSE & PERMIT TO OP...		1349	16-Oct-17	15-Dec-22	
CNST-1010	Technology Certification	22	02-May-22*	31-May-22	
CLIC-1020	NRC Inspection During Construction	904	01-Jul-19	15-Dec-22	ELIC-1379

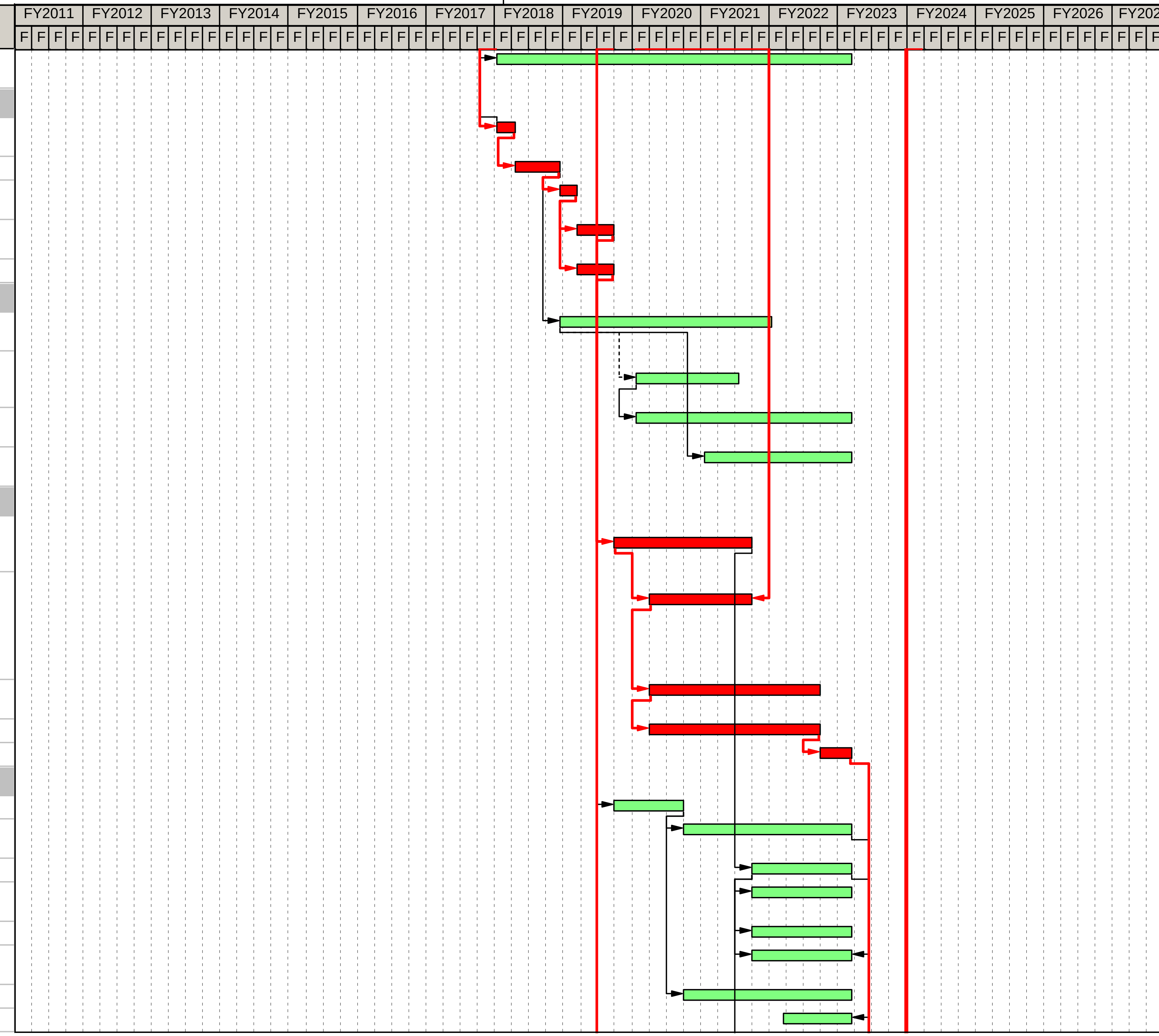


Actual Work | Critical Remaining Work | Remaining Work | Milestone

TASK filter: All Activities

28-Jan-11 10:24

Activity ID	Activity Name	Original Duration	Start	Finish	Predecessors
CNST-1000	Design Support During Construction	1349	16-Oct-17	15-Dec-22	CNST-1025
EARLY SITE WORK		445	16-Oct-17	28-Jun-19	
CNST-1025	Mobilize Site Work Contractor	70	16-Oct-17	19-Jan-18	EACQ-1830, ELIC-1220
CNST-1035	Civil / Underground Utilities	170	22-Jan-18	14-Sep-18	CNST-1025
CNST-1045	Construction Facilities / BOP Buildings	65	17-Sep-18	14-Dec-18	CNST-1035
CNST-1055	Rebar & Embedments Delivery	140	17-Dec-18	28-Jun-19	CNST-1045
CNST-1065	Excavation / Mud Mat	140	17-Dec-18	28-Jun-19	CNST-1045
BOP		1109	17-Sep-18	15-Dec-22	
CNST-1030	Buildings & Balance of Plant Structures	805	17-Sep-18	15-Oct-21	CNST-1035
CNST-1040	Piping, Equipment Installation, Mech. for Structures	392	21-Oct-19*	20-Apr-21	CNST-1030
CNST-1070	Electrical Substation & Power Distribution for Structures	824	21-Oct-19	15-Dec-22	CNST-1040
CNST-1080	Instrumentation & Controls for Structures	564	19-Oct-20	15-Dec-22	CNST-1030
NSS		904	01-Jul-19	15-Dec-22	
CNST-1110	Civil / Structural Architectural	523	01-Jul-19	30-Jun-21	ELIC-1379, CNST-1065, CNST-1055
CNST-1130	Piping, Equipment Installation, Mech	390	02-Jan-20	30-Jun-21	CNST-1110, EACQ-1850, EACQ-1175, EACQ-1035
CNST-1230	Electrical Power, Controls & Lighting	651	02-Jan-20	30-Jun-22	CNST-1130
CNST-1260	Instrumentation & Controls	651	02-Jan-20	30-Jun-22	CNST-1230
CNST-1270	Demobilization	120	01-Jul-22	15-Dec-22	CNST-1260
ECP		904	01-Jul-19	15-Dec-22	
CNST-1400	Buildings & Structures	262	01-Jul-19	30-Jun-20	CNST-1055
CNST-1410	Piping, Equipment Installation, Mech.	642	01-Jul-20	15-Dec-22	CNST-1400
CNST-1420	Steam Generator	381	01-Jul-21	15-Dec-22	CNST-1110
CNST-1430	Steam Generator Vendor Package	381	01-Jul-21	15-Dec-22	CNST-1420
CNST-1440	Main Turbines	381	01-Jul-21	15-Dec-22	CNST-1420
CNST-1450	Cooling System	381	01-Jul-21	15-Dec-22	CNST-1410, CNST-1420
CNST-1460	Electrical	642	01-Jul-20	15-Dec-22	CNST-1400
CNST-1470	Instrumentation & Controls	261	16-Dec-21	15-Dec-22	CNST-1420



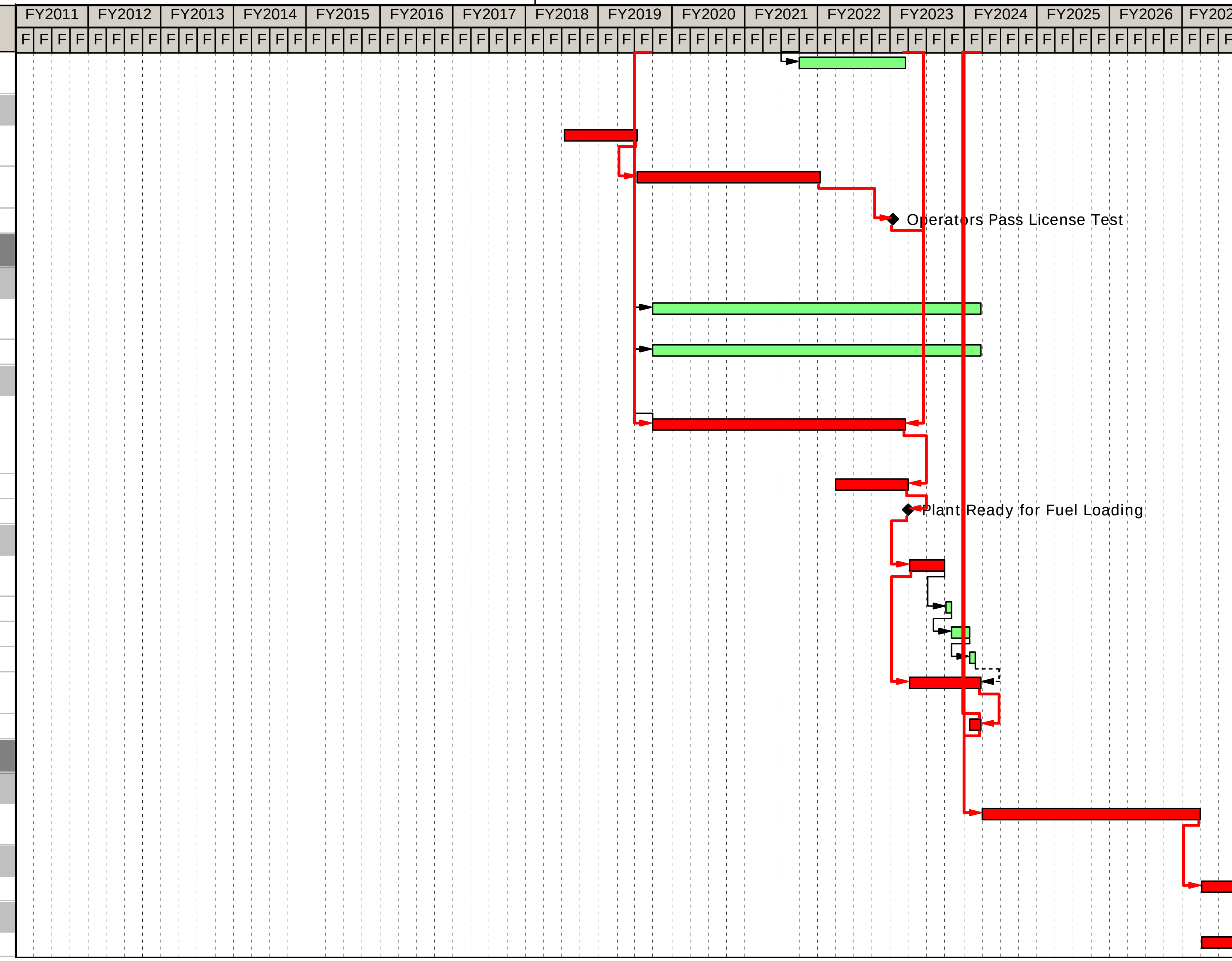
Actual Work
Critical Remaining Work
Remaining Work
Milestone

Page 4 of 5

TASK filter: All Activities

28-Jan-11 10:24

Activity ID	Activity Name	Original Duration	Start	Finish	Predecessors
CNST-1490	Main Condenser / FW Heaters	381	01-Jul-21	15-Dec-22	CNST-1420
3 66 000 - TRAINING		1175	16-Apr-18	14-Oct-22	
CTRN-1050	Simulator Installation & Testing	260	16-Apr-18*	12-Apr-19	
CTRN-1030	NRC Operator Certification Training	655	15-Apr-19	15-Oct-21	CTRN-1050
CTRN-1040	Operators Pass License Test	0		14-Oct-22*	CTRN-1030
4 00 000 - INITIAL OPERATIONS & IN...		1175	01-Jul-19	29-Dec-23	
Initial Operations & Inspection		1175	01-Jul-19	29-Dec-23	
IOPR-1000	Design Support During Startup	1175	01-Jul-19	29-Dec-23	IOPR-1030
IOPR-1010	Owner's Startup Costs	1175	01-Jul-19	29-Dec-23	IOPR-1030
4 72 000 - PRE-COMMISSIONING (CO...		915	01-Jul-19	30-Dec-22	
IOPR-1030	Pre-Commissioning	904	01-Jul-19	15-Dec-22	CNST-1065, CTRN-1040, CNST-1270
IOPR-1050	Pre-Operational Testing	262	30-Dec-21	30-Dec-22	IOPR-1030
IOPR-1060	Plant Ready for Fuel Loading	0		30-Dec-22	IOPR-1050
4 73 000 -COMMISSIONING & START...		260	02-Jan-23	29-Dec-23	
IOPR-1160	Initial Fuel Load to Lower Power Testing	130	02-Jan-23	30-Jun-23	IOPR-1060
IOPR-1170	1st Sync to Grid	22	03-Jul-23	01-Aug-23	IOPR-1160
IOPR-1180	Power Ascension Testing	67	02-Aug-23	02-Nov-23	IOPR-1170
IOPR-1190	Maintenance outage	21	03-Nov-23	01-Dec-23	IOPR-1180
IOPR-1150	NSS	260	02-Jan-23	29-Dec-23	IOPR-1160, IOPR-1190
IOPR-1200	Plant Acceptance testing	45	30-Oct-23	29-Dec-23	IOPR-1150
5 00 000 - OPERATE COMMERCIALLY		914	01-Jan-24	01-Jul-27	
5 74 000 - OPERATE PLANT		785	01-Jan-24	01-Jan-27	
OPRC-1020	Operate Plant	785	01-Jan-24	01-Jan-27	IOPR-1250, IOPR-1200
5 76 000 - SHUTDOWN & INSPECTIONS		129	04-Jan-27	01-Jul-27	
OPRC-2020	Shutdown & Inspections	129	04-Jan-27	01-Jul-27	OPRC-1020
5 75 000 - MAINTAIN PLANT		129	04-Jan-27	01-Jul-27	
OPRC-3020	Maintain Plant	129	04-Jan-27	01-Jul-27	OPRC-2020



Actual Work
Critical Remaining Work
Remaining Work
◆ Milestone

Page 5 of 5

TASK filter: All Activities