6.0 Systems Integration

The Program's Systems Integration function provide a disciplined approach to the research, design, development and validation of complex systems to ensure that requirements are identified, verified, and met while minimizing the impact on cost and schedule of unanticipated events and interactions. Systems Integration supports Program evolution and EGS development. The desired end point is achievement and validation of technology targets from which industry can develop a well-integrated EGS that reliably and cost-effectively provides electricity.

The Systems Integrator provides the tools and processes necessary to integrate and measure progress toward Program goals. These tools and processes, tailored to the particular requirements of a robust, long-term R&D program, take advantage of experiences and lessons learned from industry, academia, international sources, and other Federal agencies (e.g., the U.S. Department of Defense [DOD] and the National Aeronautics and Space Administration [NASA]).

6.1 Systems Integration Technical Goal

Goal: To support the Program in the achievement and verification of the capabilities required to effectively reach technology readiness in 2015 at the minimum cost.

6.2 Systems Integration Barriers to Commercialization

The following details the various technical and programmatic barriers that must be overcome to attain the DOE Geothermal Program Systems Integration goal and objectives.

Barrier Z: **Program Complexity** – GTP will include numerous projects addressing a variety of technological disciplines, many of which are on the leading edge of technology. Both vertical and horizontal integration will be necessary to integrate the Program under a unified system and to ensure integrated management and optimization of workflow across organizational boundaries. Completeness is important, because a true assessment of the sufficiency of program efforts against the requirements can only be made if the entire Program is represented.

Barrier AA: **Adapting System Integration Functions to an R&D Program** – Systems integration has most often been applied to the design, development, production, and maintenance of large, complex acquisition or construction projects. Implementing systems integration within an ongoing R&D program without delaying or disrupting current efforts represents a significant challenge, especially when the process has not been institutionalized within the organization.

Barrier AB: **Inherent Uncertainty in R&D** – Most systems integration and engineering efforts have been applied to large hardware and software acquisition projects, not R&D programs. Given the inherent uncertainties with regard to achieving desired outcomes from the research and development of new technologies, tailoring the systems integration procedures and tools to the R&D paradigm will be a challenge. Gaining Program and stakeholder acceptance of these processes adds value and will be important to both Program Element and overall Program success.

Barrier AC: **Accessibility/Availability of Technical Information** – The cost-effective availability and accessibility of the most up-to-date technical results are necessary to support programmatic decision-making. Within the Program, technical information relevant to a particular issue must be collected from the original developers, often dispersed through many organizations, who may not have initially considered how the information would factor into management decision-making .To ensure that results from many sources are technically and practically realistic, these diverse technical results require a vetting process.

Barrier AD: **Need to Control Guiding Documents** – Technical and programmatic goals, objectives, and targets need to be developed in order to provide structure to both R&D and Validation activities. Once these elements are established, it is critical to ensure that changes are not made without proper coordination by program staff and approval by the program manager. All related documentation needs to be maintained in alignment with these programmatic elements.

6.3 Systems Integration Technical Objectives

The objectives of the GTP Systems Integration are as follows:

- Develop Program Performance Baseline.
- Provide value-added analyses, with resultant recommendations which aid the R&D focus and portfolio decision-making processes of the Program.
- Provide periodic independent verification of progress toward key technical targets and project performance, and ensure that the overall course of R&D satisfies Program requirements.
- Improve Program effectiveness and efficiency by the appropriate implementation of systems engineering and management processes, including risk management and configuration management/change control.
- Provide processes and products that review and document the progress of the program on an annual basis.

6.4 Systems Integration Technical Approach

Systems Integration provides technical and programmatic support to the Program by:

- Establishing, validating, and maintaining the Integrated Baseline as EGS technologies and systems are advanced from concept to technology readiness;
- Providing consistent and independent (when required) results of analyses to support programmatic decisions;
- Verifying that technology progress and results meet Program requirements;
- Implementing formal systems engineering processes that provide the Program Manager with ample insight into, and control of, the entire Program; and
- Supporting the implementation of strong program engineering and management processes.

Figure 6.1 is a graphic description of how the baseline, analysis, and verification functions interrelate, along with their supporting process and management disciplines.

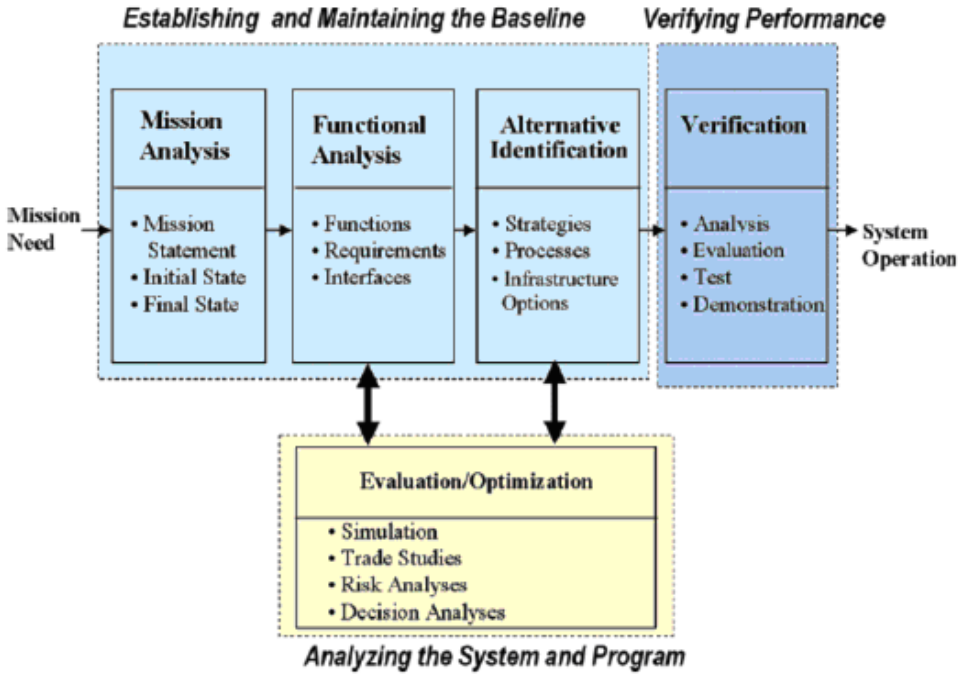

Figure 6.1. Systems Integration Approach Overview

6.4.1 Systems Integration Integrated Technical and Programmatic Baseline

Integrated Baseline: The Integrated Baseline (IB) is a tool and process that helps manage the Program by ensuring that (1) RD&D and analysis projects proper address all of the Program requirements and (2) that the cost, schedule, and performance of the Program and Program projects remain understood and controlled. The first objective ensures that the Program is pursuing work that advances Program mission and the second ensures that Program work is correctly performed.

These two components are represented by the Technical Baseline (TB) and Programmatic Baseline (PB), respectively, which are then linked by the technical objectives of the Program to provide the "integrated" aspects of the overall baseline. As shown in Figure 6.2, the IB is derived from the overarching documents that guide DOE research programs.

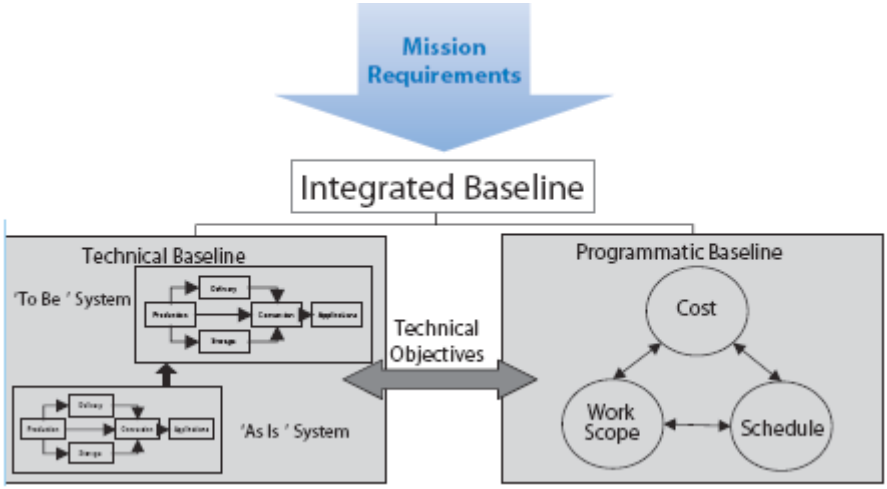

Figure 6.2. The Integrated Baseline

Once approved, the IB becomes the control version against which the Program is assessed by external peer reviewers. The Systems Integrator supports the Program in implementing a formal process to manage and control changes to the baseline per: budget requests and appropriations; identified changes in the market or policy context; newly relevant technical advances; and available information.

Technical Baseline: The TB provides a detailed map starting from the overall requirements, through the objectives and barriers of the individual Program elements, and finally to the task and individual project level. Requirements for the TB are drawn from the National Energy Policy, EPACT 2005, DOE Strategic Plan, and Geothermal Technologies Program Office strategic plans, among others, to ensure that Program work advances Program mission.

The TB includes the prioritization of activities, as well as information on the risk level of individual activities. Questions that can be addressed and answered using the TB include:

- Does the R&D portfolio properly address all the Program requirements?
- Are there gaps or weaknesses in coverage of technical areas?
- Are the high priority items receiving the proper level of programmatic attention?
- Are there sufficient approaches and projects in the higher risk areas to mitigate those risks?
- When funding or focus changes, in what areas should the Program redistribute, add, or decrease resources?

The TB serves as a complete reference set of technical data describing the current ("as-is") state of the Program infrastructure. The CORE® systems engineering tool in which the TB is hosted also

has the capability to represent desired ("to-be") end states, in terms of development and deployment scenarios or expected descriptions and at different points in time over the next several decades. Using this feature, the TB can be used to identify and evaluate alternative pathways for meeting the needs/requirements or responding to new programmatic directions. The process of reviewing and validating requirements and aligning the Program with those requirements is recurrent to accommodate advances in R&D, as well as changes that result from the evolution of markets or policies, budget changes, or programmatic focus.

Programmatic Baseline: To ensure that the Program correctly performing activities, the PB provides a tool and process to track the cost, schedule, and performance of the Program at multiple work breakdown structure levels (Figure 6.3). The PB describes these efforts in terms of budget, milestones, and scope. The PB also identifies the dependencies among the activities through an integrated work breakdown structure (WBS) and master schedule. Loaded with the resources necessary to accomplish the work (funding, personnel, tools, facilities, etc.), the PB allows assessment of shortfalls and effects of shifting priorities or funding changes. DOE staff within each Program element uses the PB to address and answer questions, such as:

- Are budgets and schedules on track – for the Program, a Program element, a task, or an individual project?
- If there is a delay in a particular activity's schedule, what is the cost and schedule impact on dependent or related activities?
- If funding is reduced in an area, what is the impact to the schedule, and if resources are reallocated, how are schedules affected?
- How does the Program scope change with respect to different funding-level scenarios?

Once proposed changes to the PB are approved through the Change Control Board, the Systems Integrator updates and maintains the PB.

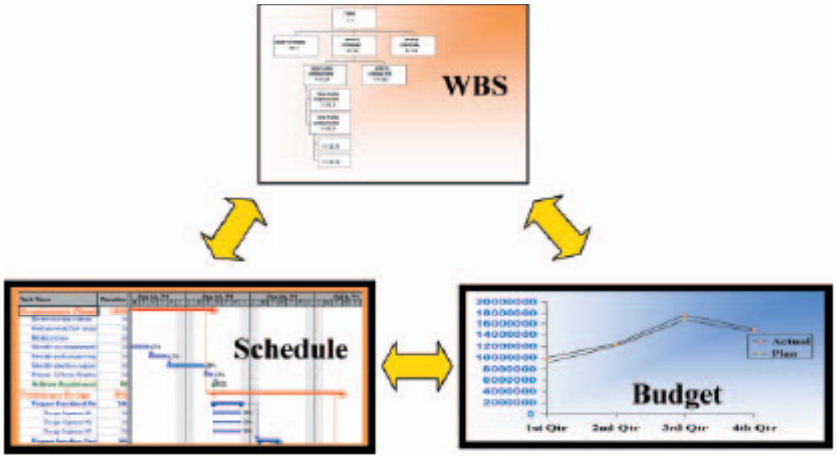

Figure 6.3. Programmatic Baseline Concept

6.4.2 Systems Integration Analysis

Systems Integration supports the review and assessment of alternatives for satisfying the needs of a future EGS system and the Program's progress, a component necessary in setting desired end-states for the TB and to study trade-offs between specific targets. This systems integration provides independent analysis, when required, to help ensure objective and substantiated decisions by the Program.

Additionally, Systems Integration supports the analysis efforts of Program's Planning and Analysis Lead as related to the overall Systems Analysis program element. These efforts include A) Development of (and revisions to) the Systems Analysis Work Breakdown Structure (WBS), which provides the plan and funding estimates for all analysis and modeling activities through 2015; and B) Conducting Systems Analysis Working Groups. These work groups are important activities in terms of dissemination of Systems Analysis products and analysis community input to, and review of, the Systems Analysis program element.

6.4.3 Technical Performance Verification

Technical performance verification will be accomplished through analysis, testing, and/or demonstration. As the Program develops new technologies and produces research results, Systems Integration facilitates technical reviews at key stages to evaluate strategic fit with Program objectives, technical, economic, and market potential, and environmental, health, and safety considerations and additional development plans.

Verification criteria and approaches will vary according to technology maturity; at early stages of development, information available to evaluate concepts is likely to be more general and have higher uncertainty than that available at later stages. Information stemming from these reviews will be used to re-evaluate the baseline. In some cases, Systems Integration convenes technical review panels of peer experts to provide an independent assessment and recommendation to DOE for consideration during the decision-making process. This is particularly true for major Go/No-Go decisions of the Program, as well as when an assessment of progress toward one of the key technical targets of the Program is warranted.

The Systems Integrator works closely with the DOE Technology Development Managers to bring knowledge of system-level requirements that will lead to verification and to review criteria for planning and execution which will guarantee performance verification. In particular, the Systems Integrator supports reviews of the following Program activities:

- Peer review (generally annually) for all projects and activities
- Independent review panels for key Program milestones and Go/No-Go decisions
- Stage Gate reviews at key progress points for significant projects.

6.4.4 Systems Integration and Management

Systems Engineering Management: Systems Integration supports the Program by aiding implementation of several key processes, two of which are described below:

Risk Management: Systems Integration supports implementation of a risk management process to identify potential Program risks and determine actions that will mitigate the impact of those risks. The Risk Management Plan (RMP) describes methods for: identifying, assessing, prioritizing, and analyzing risk drivers; developing risk-handling plans; and planning for adequate resources to handle risk. The RMP assigns specific responsibilities for the management of risk and prescribes the documenting, monitoring, and reporting processes to be followed. A six-step risk process– awareness, identification, quantification, handling, impact determination, reporting and tracking– will be used. Throughout the life of the Program, the Systems Integrator helps identify "potential" risks, focusing on the critical areas that could affect the outcome of the Program such as:

- System Requirements;
- Technology Capability;
- Budget and Funding Management;
- Schedule;
- Modeling and Simulation Accuracy;
- Environment, Safety, and Health; and
- Stakeholder, Legal, and Regulatory Issues.

Configuration Management: Systems Integration manages the evolving configuration of, and continuously monitors and controls the Technical Baseline. Changes to the Technical Baseline and the Programmatic Baseline (the approved work scope, schedule, and cost) must be controlled to ensure that all work being performed is consistent with the approved technical requirements and the current configuration, and that potential impacts throughout the Integrated Baseline are considered before actions are taken. For sufficiently complex programs, a formal change control process ensures that the potential impacts of proposed changes to either the Technical Baseline or the Programmatic Baseline are controlled. Controlled is defined as having been evaluated, coordinated, reviewed, approved, and documented. The decision-making body within the Program that approves proposed changes is known as the Change Control Board. The procedures and processes will be documented in a Configuration Management Plan.

6.4.5 Program Support

Systems Integration provides analyses and recommends DOE-sponsored activities to make sure R&D results are shared throughout the geothermal community, thus ensuring the development of the necessary technological capabilities at the lowest possible cost. Support is provided to the overall Program in the following areas:

- Annual Merit Review – Systems Integration will inform the conduct of the annual review of the Program, during which DOE-funded projects deliver oral or visual presentations. A team

of peer reviewers, skilled in the particular disciplines, evaluates selected projects.

- Annual Progress Report – This annual report will summarize the objectives, approach, technical accomplishments, and future plans for each of the projects funded by the Program.

6.5 Systems Integration Programmatic Status

The following table summarizes Systems Integration activities.

Table 6.1. Fiscal Year 08 / Fiscal Year 09 Systems Integration Activities

Activities	Description
Integrated Baseline	**Technical Baseline:** Establish an initial version of the technical baseline, containing requirements, tasks, objectives, barriers, technical targets and projects, in CORE®. **Programmatic Baseline:** Conduct a Budget Estimation exercise for the entire Program, yielding a detailed WBS, schedule and budget estimates for each Program Element and enter into the CORE® baseline. Support the development of an overall Program Master Schedule
Systems Analysis	Support the Planning and Analysis Lead in technical management and monitoring of analysis projects (e.g., develop the Systems Analysis Plan.
Verification of Technical Performance	Organize peer review activities at the Annual Merit Review and issue the review report. Choose and acquire resources to perform independent assessment of progress on key technical targets (as required).
Systems Engineering	Produce the Configuration Management Plan. Facilitate Change Control processes and boards to update the Multi-Year Plan. Produce the Risk Management Plan and initiate pathfinder risk analysis activities to support the budget process.
Program Support	Conduct the Annual Merit Review meeting. Publish the Annual Progress Report.

Table 6.2 summarizes the Systems Integration Program status.

Table 6.2. Systems Integration Program Status Summary		
Barriers	**Program Needs**	**Program Status**
Barrier Z: Program Complexity	Develop an integrated technical and programmatic baseline to provide a detailed roadmap starting from the overall requirements, through the objectives and barriers of the individual Program elements, and finally to the task and individual project level.	The status of the integrated baseline is subordinate to technical decisions that will drive the full EGS program.
Barrier AA: Adapting System Integration Functions to an R&D Program	Development of, and revisions to, the Systems Analysis Work Breakdown Structure (WBS) — the WBS provides the plan and funding estimates for all analysis and modeling activities through 2015.	Conduct Systems Analysis Working Groups — these are important activities in terms of dissemination of Systems Analysis products, as well as analysis community input to, and review of, the Systems Analysis program element.
Barrier AB: Inherent Uncertainty in R&D	Develop a detailed systems-level risk analysis model	The GTP has performed a preliminary risk analysis project and has begun updating its risk model and the Technology Improvement Opportunities tailored to the EGS focus of the program.
Barrier AC: Accessibility/ Availability of Technical Information	Conduct Annual Merit Review and prepare Annual Progress Report	In order to ensure the development of the necessary technological capabilities at the lowest possible cost, when available results of DOE-sponsored activities a will be shared throughout the geothermal community through the Annual Merit Review and the Annual Progress Report.
Barrier AD: Need to Control Guiding Documents	Develop the Configuration Management Plan	The GTP is in process of developing the Configuration Management Plan to ensure that all work being performed is consistent with the approved technical requirements and the current program configuration.

6.6 Systems Integration Tasks

The following table provides descriptions of Systems Integration tasks.

Table 6.3. Systems Integration Task Descriptions

Task	Description	Barriers
1	• Develop and Maintain the Integrated Baseline (IB). • Update the IB quarterly. • Support development of the Program master budget and schedule.	Z,AA,AB,AD
2	• Support Systems Analysis. • Support Systems Analysis WBS updates. • Develop a Systems Analysis Plan.	AB,AC
3	• Verify year Technical Performance. • Organize Annual Merit Review peer review activities and issue report. • Conduct Go/No-Go Reviews (as required). • Perform Stage Gate Reviews (as required). • Conduct independent Technical Target Assessments (as required).	Z,AA,AB
4	• Implement Systems Engineering. • Produce the Configuration Management Plan. • Implement Change Management/Change Control processes. • Implement Risk Management support to the Program.	Z,AA,AB,AD
5	• Conduct Annual Merit Review meeting. • Prepare the Annual Progress Report.	Z