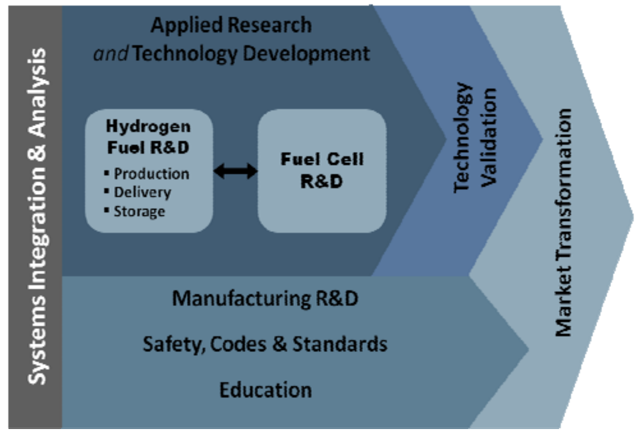
5.0 Systems Integration



The Systems Integration function of the DOE Hydrogen and Fuel Cells Program (the Program) provides independent, strategic, systems-level expertise and processes to enable system-level planning, data-driven decision-making, effective portfolio management, and program integration. System Integration ensures that system-level targets are developed, verified, and met and that the sub-programs are well-coordinated. Systems Integration provides tailored technical and programmatic support to ensure a disciplined approach to the research, design, development, and validation of complex systems. Systems Integration provides such support by employing systems engineering-based processes and practices to calibrate internal management processes for enhanced internal efficiency and overall performance. Tailored to the particular requirements of a robust, comprehensive research, development, and demonstration (RD&D) program, these tools and processes take advantage of experience and lessons learned from industry, academia, international sources, and other federal agencies [particularly the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA)]. The systems differ from DOD and NASA in that DOD and NASA's systems are for their operations (e.g., fighter jets, spacecraft), whereas the systems supported by this effort are national-scale, industry and consumer applications under investigation by the program. The systems applications include hydrogen / fuel cell energy systems for on-road light duty vehicles; material and freight handling systems; combined heat and power systems (with and without hydrogen production); backup power systems; auxiliary power units; and portable power.

5.1 Goal and Objectives

Goal

To provide an independent, strategic, systems-level framework to ensure that system-level targets are developed, verified, and met and that the various Fuel Cell Technologies Program (FCT Program) sub-programs are well-coordinated.

Objectives

- Provide periodic independent verification of progress toward key technical targets, review of project performance, and ensure that the overall course of RD&D satisfies the FCT Program needs.
- Update the FCT Program work breakdown structure (WBS) and resource loaded plan (RLP) in 2012 and in following years.
- By 2012, develop a portfolio management tool that allows the FCT Program to estimate effects of changing funding level or distribution on the expected time and effort to achieve program goals.

- By 2015, complete an analysis of hydrogen infrastructure and technical target progress for technology readiness, in cooperation with the Systems Analysis sub-program.
- Coordinate the Annual Merit Review and Peer Evaluation (AMR) meeting and report, the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), and the Program's web site (www.hydrogen.energy.gov).

5.2 Approach

Systems Integration provides technical and programmatic support to the Program by performing the following five activities: (1) systems level planning and integration (multiyear targets, work breakdown structure, and change control); (2) developing and providing tools and information necessary for portfolio analysis including risk identification and quantification; (3) systems analysis and modeling including the macro-system model (MSM); (4) verification of technical performance; and (5) coordinating the AMR, HTAC, and Program's website. See Figure 5.2.1 for a graphic description of how the planning, portfolio analysis, systems analysis, and verification functions inter-relate. Descriptions of the five tasks' activities follow in this section.

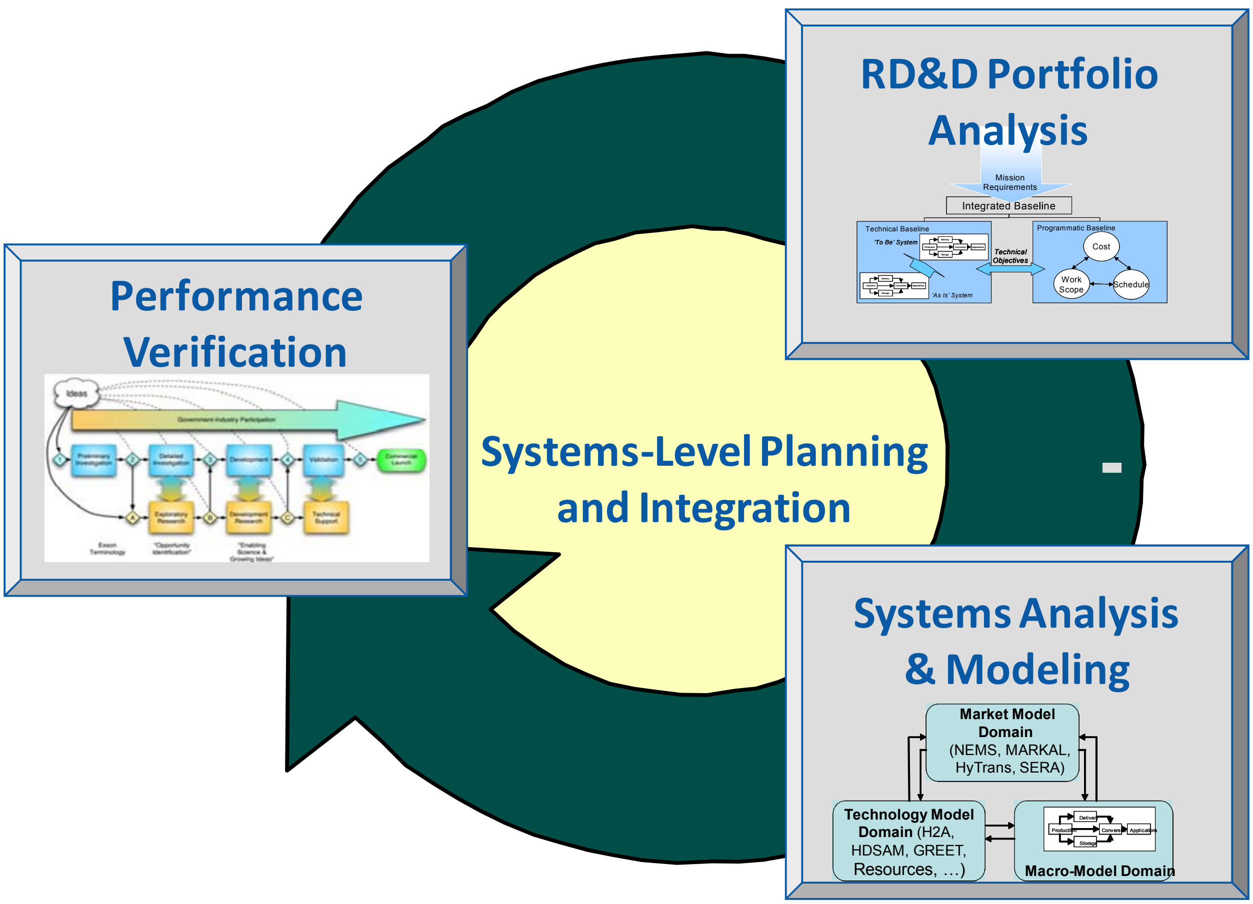


Figure 5.2.1 Systems Integration Approach Overview

System Level Planning and Integration

The FCT Program requires coordinated planning including Multi-Year Research, Development, and Demonstration (MYRD&D) plans, WBSs, and program-level RLPs. The Systems Integration function supports the FCT Program in developing, updating (including change control), and publishing those plans. Coordinated development of the plans are challenging due to the dynamic environment both technically, due to unpredictability in evolution of the technology and competing technologies, and organizationally, due to changing priorities. Another challenge is integrating the plans across multiple technology platforms.

The MYRD&D plan documents the FCT Program's objectives, approach, targets, barriers, milestones, and sub-program inputs/outputs. The Systems Integration function coordinates development and updating of the plan so that it defines the tasks necessary to meet the FCT Program's objectives; it is internally consistent; and it incorporates technology advances, program learning, and changes in direction and priority. All changes to the MYRD&D plan undergo a formal change control process that has been established to ensure that their potential impacts are evaluated, coordinated, controlled, reviewed, approved, and documented in a manner that best serves the FCT Program and its projects.

The decision-making body for approving proposed changes to the MYRD&D plan is the Change Control Board (CCB), headed by the FCT Program's Chief Engineer. All proposed changes are submitted and individually reviewed by all CCB members. Input from each member is collected and incorporated, and a meeting is held to discuss and finalize the input. Following CCB approval, the change is implemented and final approval from the FCT Program's Chief Engineer is sought. Once it is received, Systems Integration publishes the updated MYRD&D plan.

The Systems Integration function supports the development of an integrated WBS and RLP. Both are key elements necessary to manage and control a program. The WBS is a definition of the necessary work to perform the activities and achieve the targets defined in the MYRD&D plan. The WBS is built as a hierarchy that divides the effort into well-defined activities and identifies dependencies among activities. The RLP reports an estimate of the budget and schedule necessary to perform the activities defined in the WBS but does not define specific personnel, tools, facilities, or other resources.

Portfolio Analysis

Portfolio analysis is performed to assist the FCT Program in identifying the optimal portfolio of technologies and projects to achieve its performance and market targets. Factors considered include the level of benefits expected, scope, cost, schedule, and risk to realizing the program benefits. It is an iterative process that weighs benefits against costs and risks while taking into account the latest external information regarding market, technical status, and barriers. The process also incorporates the updated status of portfolio efforts based on verified, externally reviewed progress.

Systems Integration utilizes portfolio analysis tools and processes that help manage the FCT Program by ensuring that (1) RD&D and analysis projects are properly addressing all of the FCT Program requirements and (2) that the cost, schedule, and performance of the FCT Program and its projects are understood and controlled. In other words, the first ensures that the FCT Program is "doing the right things" and the second that it is "doing things right." 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 FCT Program to provide the "integrated" aspects of the overall baseline. As shown in Figure 5.2.2, an Integrated Baseline (IB) for the FCT Program was originally derived from the overarching policy, strategy, and planning documents associated with the FCT Program including the Energy Policy Act of 2005 (EPACT), the U.S. DRIVE Partnership Plan and its preceding agreements, the National Hydrogen Vision and Roadmap, the DOE Strategic Plan, individual DOE Office strategic plans, the Hydrogen and Fuel Cells Program Plan, and individual DOE Office MYRD&D Plans. It will be updated regularly to represent the FCT Program's status and targets.

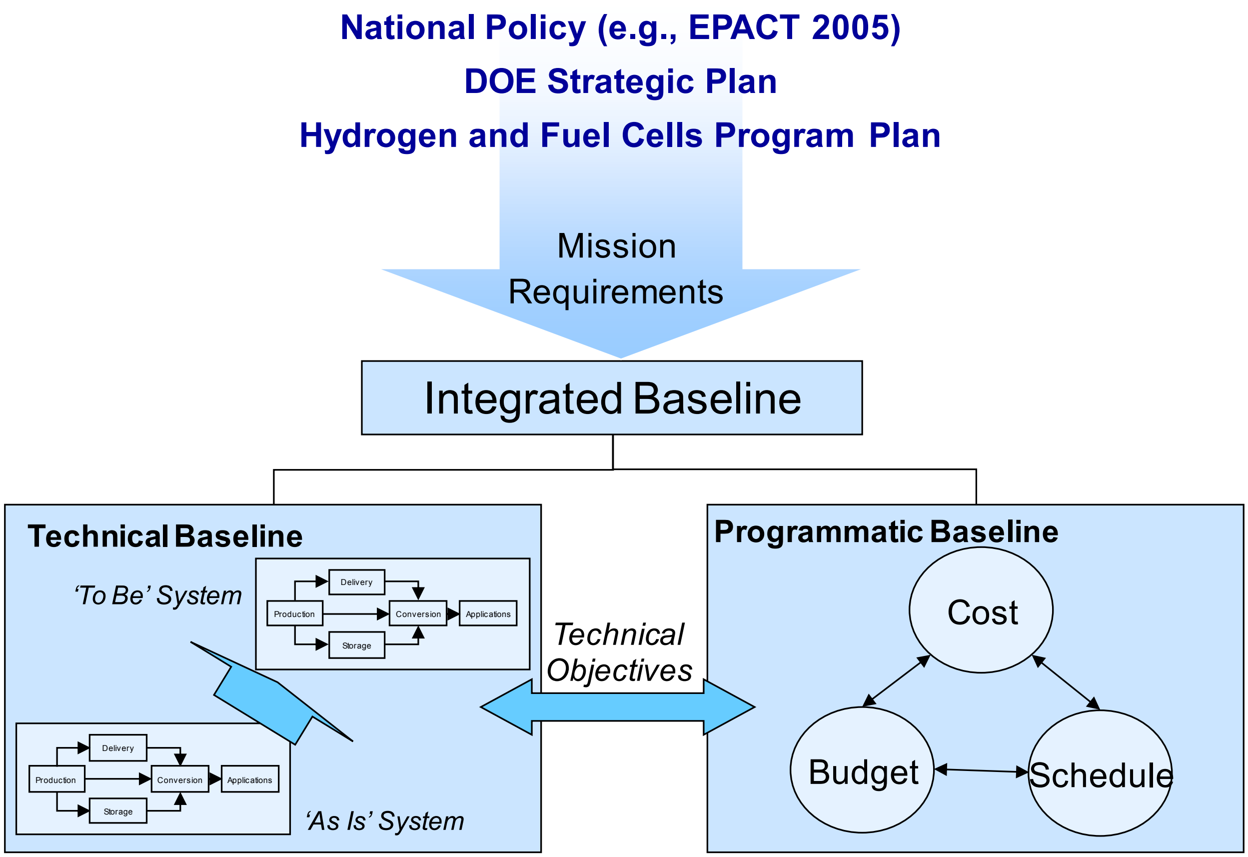


Figure 5.2.2 The Integrated Baseline

Tracking Status against Targets - Technical Baseline. To ensure that the FCT Program is "doing the right things," the TB provides a detailed map starting from the overall requirements, down through the objectives and barriers of the individual FCT Program sub-programs, and finally to the task and individual project level. 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 RD&D portfolio properly address all the FCT 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 FCT Program redistribute, add, or decrease resources?
- Are technical targets supporting system level configurations synchronized and monitored for consistency in an on-going manner?

Tracking Status against the Plan - Programmatic Baseline. To ensure that the FCT Program is "doing things right," the PB provides a tool and process to track the cost, schedule, and budget performance of the FCT Program.

Questions that can be addressed and answered using the PB include:

- Are budgets and schedules on track – for the FCT Program, an FCT sub-program, or a task?
- If there is a delay in a particular activity's schedule, what is the cost and schedule impact on dependent or related activities?
- When funding or focus changes, in what areas should the FCT Program redistribute, add, or decrease resources?
- How does the FCT Program scope change given different funding-level scenarios?
- Figure 5.2.3 illustrates the interactions between the WBS, schedule, and budget in the programmatic baseline.

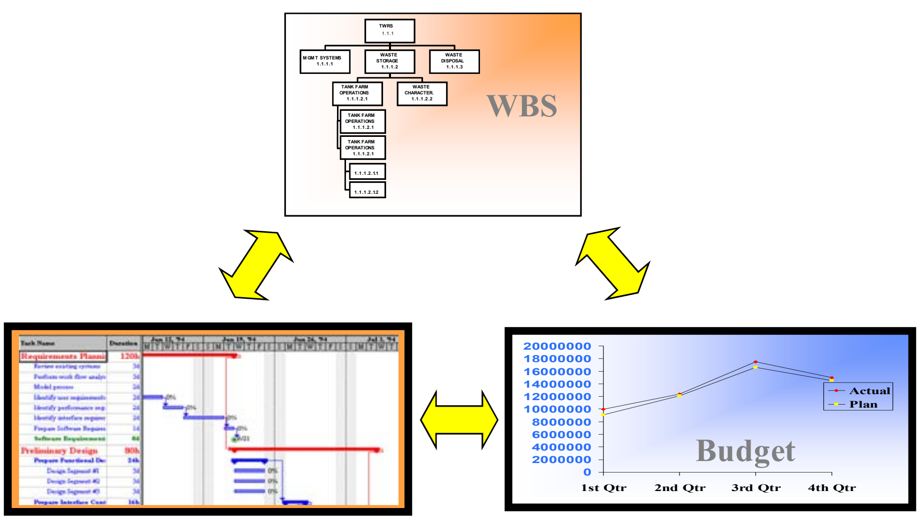


Figure 5.2.3 Programmatic Baseline Interactions

Integrated Baseline (IB). The IB tracks work against the baselines developed in the System Level Planning and Integration task described above with the intent of defining scope, schedule, and costs.

- *Scope Baseline*. Program management, with the aid of Systems Integration, establishes the boundaries of the system to be developed and operated. Within the boundaries are the overall Program mission, description of the Program and its sub-programs, and interfaces to related systems and organizations.
- *Schedule Baseline*. Systems Integration aids the FCT Program in establishing multi-year and annual milestones. The major milestones include those needed to establish the foundation of the program, and to enable key decisions to be made against documented criteria.
- *Cost Baseline*. The FCT Program establishes cost baselines, using estimates of the cost to achieve scope objectives within the defined schedule, but tempered by expectations of actual funding available through annual appropriations. The Cost Baseline is periodically updated to reflect program plan changes.

The overall approach that Systems Integration takes to bring together the TB and the PB into an IB for the Program is to first establish individual IBs for each sub-program and build these into a baseline for the overall program. Various direction and guidance documents, along with policy and direction from DOE management, guide the FCT Program staff in defining the mission requirements for the FCT Program; these mission requirements provide overarching guidance and a common framework for development of IBs for the sub-programs. As depicted in Figure 5.2.4, the TB is developed first; the PB is then derived from the TB and from other program management requirements.

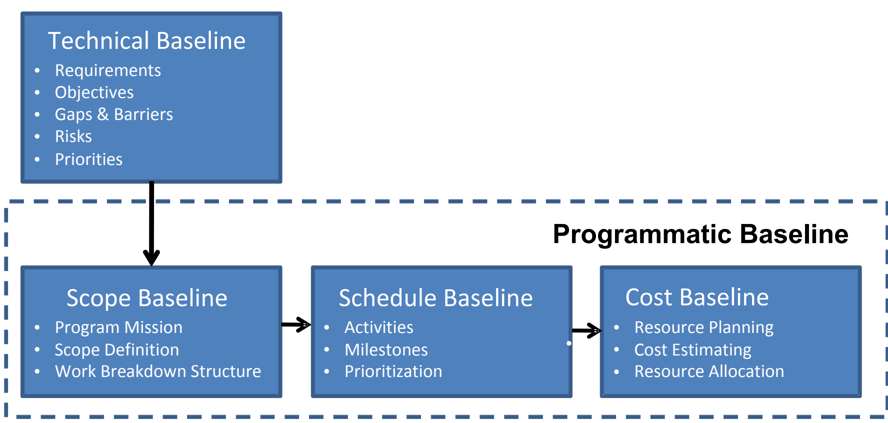


Figure 5.2.4 Establishing the Integrated Baseline

Risk Management. Systems Integration supports implementation of a risk management process to identify potential 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—risk awareness, identification, quantification, handling, impact determination, and reporting, and tracking—will be used. Throughout the life of the FCT Program, Systems Integration helps identify "potential" risks, focusing on the critical areas that could affect program outcome such as:

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

Systems Analysis and Modeling

Systems Integration assists the Systems Analysis sub-program in improving the understanding of individual components' contributions, interactions, and synergies in achieving the FCT Program's objectives. One focus area is the review and assessment of alternatives necessary to meet the needs of a future hydrogen system as well as the FCT Program's progress toward that goal. Systems Integration also provides independent analysis and analytical reviews. In addition, the Systems Integration function is responsible for development of a MSM and analyses using it.

Systems Integration provides the analysis necessary to determine the requirements of future hydrogen and fuel cell systems. The results of those analyses are used to set specific program targets. For example, Systems Integration performed the analyses necessary to set the hydrogen threshold cost and its apportionment. Systems Integration also performs parametric studies to understand tradeoffs between capital and operating costs and between production and utilization. Those analyses are important because the resulting information is necessary to define specific technology targets and understand tradeoffs between them – information necessary to help ensure objective and substantiated portfolio management decisions. Systems Integration also performs analyses of pathway cost, energy use, and emissions to assure that FCT Program targets support national goals to reduce petroleum use and greenhouse gas emissions.

Systems Integration performs independent analyses to verify and provide a definitive set of parameters for FCT Program use. These analyses include reports on the cost, energy use, and emissions of hydrogen production, delivery, and dispensing pathways. The methodology and parameters in those analyses are reviewed by FCT Program staff and external partners to guarantee their veracity. Systems Integration participates in the FCT Program's partnerships to pull in external experts to verify analytical conclusions.

Systems Integration leads the development of the MSM. The MSM was developed to act as an overarching system that provides a cross-cutting simulation capability necessary to perform analyses of production, delivery, and dispensing options while consistently propagating assumptions throughout the analysis. It was developed to meet the following specific objectives:

- To perform rapid, cross-cutting analysis in a single location by linking existing applicable models;
- To improve consistency of technology representation (i.e., consistency between models);

- To allow for consistent use of hydrogen models without requiring all users to be experts in all models;
- To support decisions regarding programmatic investments, focus of funding, and research milestones through analyses and sensitivity runs.

The MSM has a structure that links other existing and emerging models. A number of models exist to analyze components and subsystems of a hydrogen infrastructure; however, the MSM integrates some of those component and subsystem models using a common architecture to compute overall results (i.e., it is a tool that addresses the overarching hydrogen fuel infrastructure as a system). The MSM structure was inspired by the example of the federated object model (FOM), as exemplified in the DOD High Level Architecture (HLA). The FOM approach requires the explicit definition of the messages (objects and interactions) through which the models interact with their environment, providing a common communication format and structure for the models. Scalability is achieved because there is only one such interface module per model, rather than one for each pair of models.

Additionally, Systems Integration supports the Systems Analysis sub-program in a variety of efforts. These efforts include:

- Updates to the annual Analysis Portfolio – this Appendix to the Systems Analysis Plan provides information on all the analysis and modeling projects funded in the current fiscal year.
- Organization of Systems Analysis Workshops and 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 sub-program.
- Population of the Analysis Repository – this online database captures products and outputs of all the analysis and modeling projects funded by Systems Analysis, as well as other sub-programs and offices contributing to hydrogen and fuel cells.

Technical Performance Verification

As the FCT Program develops new technologies and produces research results, Systems Integration is responsible for reporting and review processes necessary to verify that selected/key technologies and system designs are on track to meet the FCT Program's cost and performance targets. To do so, Systems Integration facilitates technical reviews to evaluate the strategic fit with FCT Program objectives, technical potential, economic/market potential, and environmental, health, and safety considerations along with the plan and potential for further development. Verification is accomplished through peer reviews, analysis, testing, and/or demonstration. Criteria and approaches will vary depending on the maturity of the technology and project funding status. For example, 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. Thus, information stemming from a review will be used to re-evaluate the baseline. At later stages of development, more information is available and programmatic targets may need to be adjusted based on results from reviews.

In some cases, Systems Integration convenes technical review panels of peer experts to provide an independent assessment of technology status and potential to DOE for consideration during decision processes. Independent assessments are particularly useful for major go/no-go decisions and are helpful when an assessment of progress toward one of the key technical targets of the FCT Program is warranted. Independent reviews of the following have been completed:

- Hydrogen Production Cost Estimate Using Biomass Gasification
- 1–10 kW Stationary Combined Heat and Power Systems Status and Technical Potential
- Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis
- Fuel Cell System Cost for Transportation—2008 Cost Estimate
- Go/No-Go Recommendation for Sodium Borohydride for On-Board Vehicular Hydrogen Storage
- Measurement of Hydrogen Production Rate Based on Dew Point Temperatures
- Cryo-compressed Hydrogen Storage for Vehicular Applications
- Distributed Hydrogen Production from Natural Gas
- Fuel Cell System for Transportation—2005 Cost Estimate
- On-Board Fuel Processing Go/No-Go Decision

Reports from those reviews are available at http://www.hydrogen.energy.gov/peer_reviews.html.

In addition, Systems Integration works closely with the DOE Technology Development Managers to facilitate reviews based on system-level requirements and review criteria. In particular, the Systems Integration function develops a report compiling all reviewer comments and scores during the AMR. The Systems Integration sub-program is also responsible for the annual progress report that summarizes the objectives, approach, technical accomplishments, and future plans for each of the Program's projects in professional journal format. Systems Integration also conducts stage gate reviews at key progress points for significant projects.

Program Support

Systems Integration provides analyses and recommends DOE-sponsored activities to make sure that RD&D results are shared throughout the technical community, thus ensuring the further development of the requisite technologies. Specific support is provided to the overall Program in the following areas:

- AMR – Systems Integration coordinates the annual review of the Program, during which primary investigators from typically 300 funded projects present their results in oral or poster formats. In addition, a team of ~200 peer reviewers evaluate approximately two-thirds of the presented projects for feedback to the Program. More information about the AMR is available at http://www.annualmeritreview.energy.gov/
- HTAC – Systems Integration provides coordination and technical support to this Federal Advisory Committee Act (FACA)-level committee which reviews DOE efforts in hydrogen and fuel cell RD&D and provides information and recommendations to the Secretary of Energy. More information about the HTAC is available at http://www.hydrogen.energy.gov/advisory_htac.html

- DOE Hydrogen and Fuel Cells Program Website – This website provides a one-stop-shop for all of the hydrogen and fuel cell activities of DOE, across the offices of Energy Efficiency and Renewable Energy (EERE), Fossil Energy (FE), Nuclear Energy (NE), and Science (SC). The site is available at http://www.hydrogen.energy.gov/.

5.3 Programmatic Status

Table 5.3.1 provides the current set of Systems Integration activities.

Table 5.3.1 Current FY12 Systems Integration Activities

Activities	Description
Systems Level Planning and Integration	• Coordination of an update to the Multi-Year RD&D Plan including update coordination, facilitating change control processes and boards, and publication. • Initiation of an update to the FCT Program's WBS and RLP.
Portfolio Analysis	• Initiation of an update to the integrated baseline. • Completion of technical uncertainty assessments of fuel cells for vehicles.
Systems Analysis and Modeling	• Development of pathway parameter tables and results for combined heat, power, and hydrogen systems. • Analysis of 'tipping' points in hydrogen transition scenarios. • Addition of combined heat, power, and hydrogen systems to the HyPro model. • Updates to the MSM as linked models are updated. • Addition of MSM capabilities (e.g., compressed hydrogen gas and cryo-compressed trucks) and user features (e.g., outputs in the graphical user interface).
Verification of Technical Performance	• Publication of the AMR report. • Coordination of an independent review of cost of hydrogen produced from biomass using gasification.
Program Support	• Coordination of the AMR meeting. • Publication of the Annual Progress Report. • Coordination of the Hydrogen and Fuel Cells Technical Advisory Committee. • Providing timely and value-added updates to the DOE Hydrogen and Fuel Cells Program website.

5.4 Challenges

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

A. Program Complexity.

The Program has targets spanning multiple sectors and is comprised of nearly 300 projects spread across different organizations. Those projects address a variety of technological disciplines, many of which are on the leading edge of technology. Further complicating the ability to properly integrate the Program is the geographical dispersal of these organizations, its relatively long-term duration, and the multitude of external stakeholders. Both vertical and horizontal integration is necessary to integrate the Program under a unified system and to ensure integrated management and optimization of work flow across organizational boundaries. The four DOE offices (EERE, FE, NE, and SC) and other programs and agencies (e.g., Department of Transportation) that are involved in hydrogen and fuel cell work have their own baselining and scheduling requirements, which must be consistent and interrelated.

B. Adapting System Integration Functions to an RD&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 RD&D program without delaying or disrupting current efforts represents a significant challenge, especially when the process has not been institutionalized within the organization.

C. Inherent Unpredictability of RD&D.

Most systems integration and engineering efforts have been applied to large hardware and software acquisition projects, not RD&D programs. Given the inherent unpredictability of achieving desired outcomes from the R&D of new technologies, tailoring the systems integration procedures and tools to the RD&D paradigm is a challenge. Obtaining Program and stakeholder acceptance of these processes as value-added and important to both sub-program and overall Program success is also a challenge.

D. Unpredictability of competing technologies' future performance.

The potential improvements to the incumbent technologies and emerging competing technologies are unpredictable. In addition, resource supplies are uncertain and the world-wide markets are unpredictable so the future costs of competing technologies are unknown. The overall unpredictability makes target setting and tracking challenging.

E. 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 a wide array of sources—from people in different organizations, who developed it originally without necessarily considering its role in management decision-making. To ensure that results from many sources are technically and practically realistic, these diverse technical results require a vetting process.

5.5 Task Descriptions

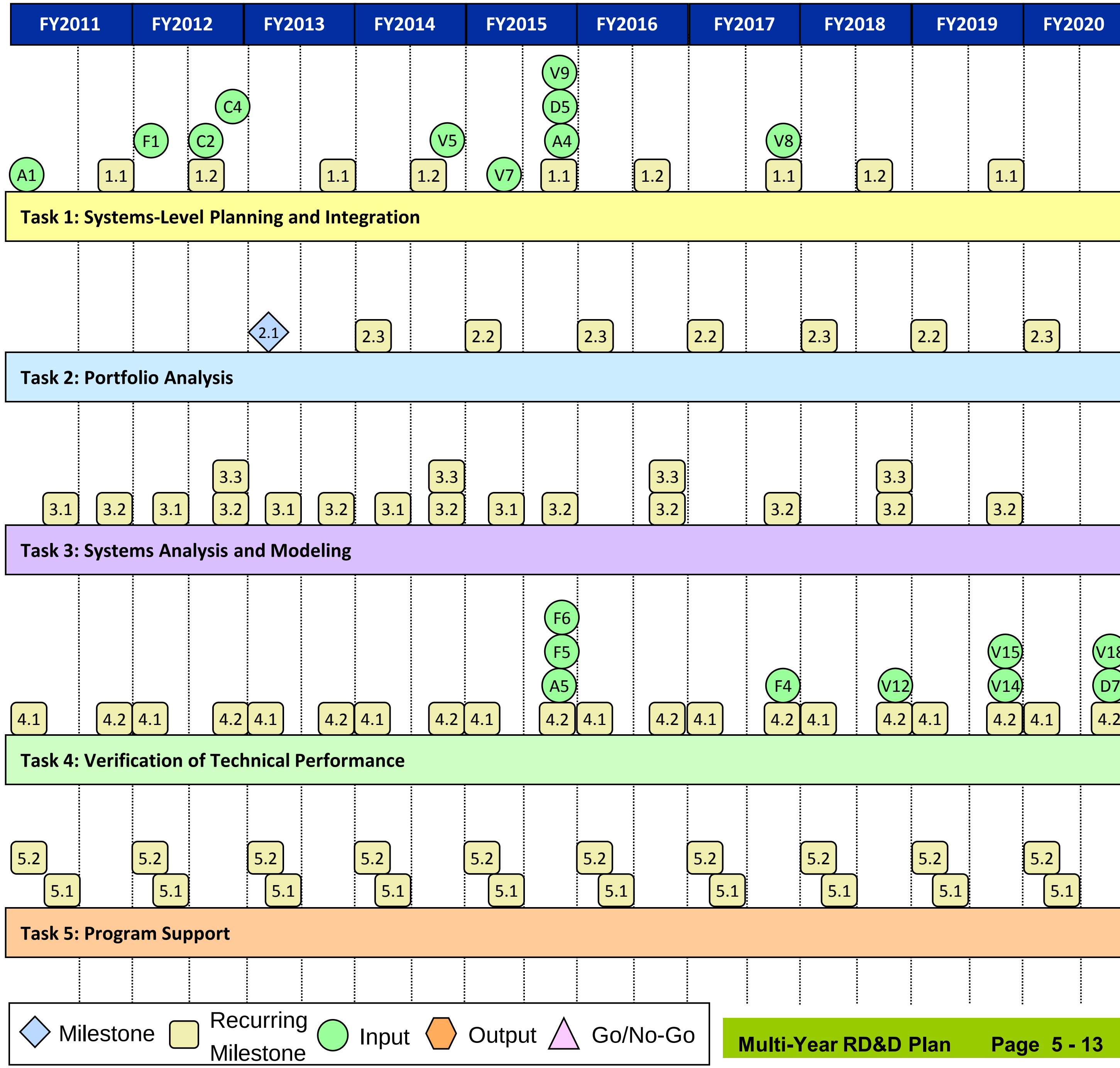
The task descriptions are presented in Table 5.5.1.

Table 5.5.1 Task Descriptions		
Task	**Description**	**Challenges**
1	Systems Level Planning and Integration • Update the FCT Program's Multi-Year Plan. • Update the FCT Program's WBS and RLP. • Continue Change Management/Change Control processes.	A, B
2	Portfolio Analysis • Support updates to the FCT Program master budget and schedule. • Analyze the effect of variances in performance and funding on the schedule. • Continue uncertainty assessments.	A, B, C
3	Systems Analysis and Modeling • Develop and maintain the MSM infrastructure. • Support of the analysis community in use of the MSM. • Analyze pathways to identify gaps and other performance issues. • Provide other system modeling support .	C, D, E
4	Verification of Technical Performance • Perform Stage Gate Reviews. • Conduct independent technical target assessments. • Publish AMR report.	A, B, C
5	Program Support • Conduct the Annual Merit Review and Peer Evaluation Meeting. • Publish the Annual Progress Report. • Support HTAC technical needs and reporting. • Update DOE Program websites.	A, B

5.6 Milestones

The following chart shows the interrelationship of milestones, tasks, and supporting inputs from other sub-programs for the Systems Integration function through FY2020. The inputs/outputs are also summarized in Appendix B.

Systems Integration Milestone Chart



Task 1: Systems-Level Planning and Integration	
1.1	Updates to the MYRD&D Plan (4Q, 2011; 4Q, 2013; 4Q, 2015; 4Q, 2017; 4Q, 2019)
1.2	Updates to WBS and RLP (3Q, 2012; 3Q, 2014; 3Q, 2016; 3Q, 2018)

Task 2: Portfolio Analysis	
2.1	Improved system for tracking programmatic baseline (1Q, 2013)
2.2	Updates to programmatic baseline (1Q, 2015; 1Q, 2017; 1Q, 2019)
2.3	Updates to programmatic targets (1Q, 2014; 1Q, 2016; 1Q, 2018; 1Q, 2020)

Task 3: Systems Analysis and Modeling	
3.1	Analysis Portfolio and Analysis Repository annual updates. (2Q, 2011; 2Q, 2012; 2Q, 2013; 2Q, 2014; 2Q, 2015)
3.2	MSM updates. (4Q, 2011; 4Q, 2012; 4Q, 2013; 4Q, 2014; 4Q, 2015; 4Q, 2016; 4Q, 2017; 4Q, 2018; 4Q, 2019)
3.3	Updates to pathways cost, energy use, and emissions report (4Q, 2012; 4Q, 2014; 4Q, 2016; 4Q, 2018)

Task 4: Verification of Technical Performance	
4.1	Annual Merit Review Peer Review Report published. (1Q, 2011; 1Q, 2012; 1Q, 2013; 1Q, 2014; 1Q, 2015; 1Q, 2016; 1Q, 2017; 1Q, 2018; 1Q, 2019; 1Q, 2020)
4.2	Independent Reviews of progress on Technical Targets. (4Q, 2011; 4Q, 2012; 4Q, 2013; 4Q, 2014; 4Q, 2015; 4Q, 2016; 4Q, 2017; 4Q, 2018; 4Q, 2019; 4Q, 2020)

Task 5: Program Support	
5.1	Produce Annual Progress Report. (2Q, 2011; 2Q, 2012; 2Q, 2013; 2Q, 2014; 2Q, 2015; 2Q, 2016; 2Q, 2017; 2Q, 2018; 2Q, 2019; 2Q, 2020)
5.2	Facilitate HTAC meetings and provide technical support (1Q, 2011; 1Q, 2012; 1Q, 2013; 1Q, 2014; 1Q, 2015; 1Q, 2016; 1Q, 2017; 1Q, 2018; 1Q, 2019; 1Q, 2020)

Outputs

Note: None for Systems Integration. Per agreement in FY05, System Integration outputs/products are for the entire Program, not individual sub-programs, so they are not shown individually and sub-programs do not show them as inputs.

Inputs

A1 Input from Systems Analysis: Issue a report on the status of the technologies and infrastructure to meet the demands for hydrogen fuel and vehicles. (1Q, 2011)

A4 Input from Systems Analysis: Issue a report on the results of the infrastructure analysis for the long term technologies and requirements for technology readiness. (4Q, 2015)

A5 Input from Systems Analysis: Issue report of the environmental analysis of the Hydrogen and Fuel Cells Program. (4Q, 2015)

C2 Input from Safety, Codes, and Standards: Hydrogen fuel quality standard (SAE J2719). (3Q, 2012)

C4 Input from Safety, Codes, and Standards: Updated materials compatibility technical reference manual. (4Q, 2012)

D5 Input from Delivery: Provide options that meet <$4/gge for hydrogen delivery from the point of production to the point of use for emerging regional consumer and fleet vehicle markets. (4Q, 2015)

D7 Input from Delivery: Provide options that meet <$2/gge for hydrogen delivery from the point of production to the point of use in consumer vehicles. (4Q, 2020)

F1 Input from Fuel Cells: Cost of the baseline automotive fuel cell system. (1Q, 2012)

F4 Input from Fuel Cells: Provide automotive stack test data from documented sources indicating performance status. (4Q, 2017)

F5 Input from Fuel Cells: Provide micro-combined heat and power system test data from documented sources indicating performance status. (4Q, 2015)

F6 Input from Fuel Cells: Provide auxiliary power unit system test data from documented sources indicating performance status. (4Q, 2015)

V5 Input from Technology Validation: Report on validation of stationary fuel cell system that co-produces hydrogen and electricity with 40,000-hour durability while maintaining a minimum of 40% overall efficiency. (4Q, 2014)

V7 Input from Technology Validation: Report on validation of a large scale (>100 kg/day) integrated wind-to-hydrogen production system. (2Q, 2015)

V8 Input from Technology Validation: Complete validation of commercial fuel cell combined heat and power systems that demonstrate 45% efficiency and 50,000 hour durability. (4Q, 2017)

V9 Input from Technology Validation: Report on the validation of residential fuel cell micro combined heat and power systems that demonstrate 40% efficiency and 25,000 hour durability. (4Q, 2015)

V12 Input from Technology Validation: Validate distributed production of hydrogen from renewable liquids at a projected cost of $5.00/gge and from electrolysis at a projected cost of $3.70 with an added delivery cost of <$4/gge. (4Q, 2018)

V14 Input from Technology Validation: Report on the status of validation of 5,000 hour durability target. (4Q, 2019)

V15 Input from Technology Validation: Validate onboard storage system achieving 5.5% weight capacity and an energy density of 1,300 Wh/L. (4Q, 2019)

V18 Input from Technology Validation: Validate large-scale system for grid energy storage that integrates renewable hydrogen generation and storage with fuel cell power generation by operating for more than 10,000 hours with a round-trip efficiency of 40%. (4Q, 2020)