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Systems Integration and the Department of Energy's Hydrogen Program

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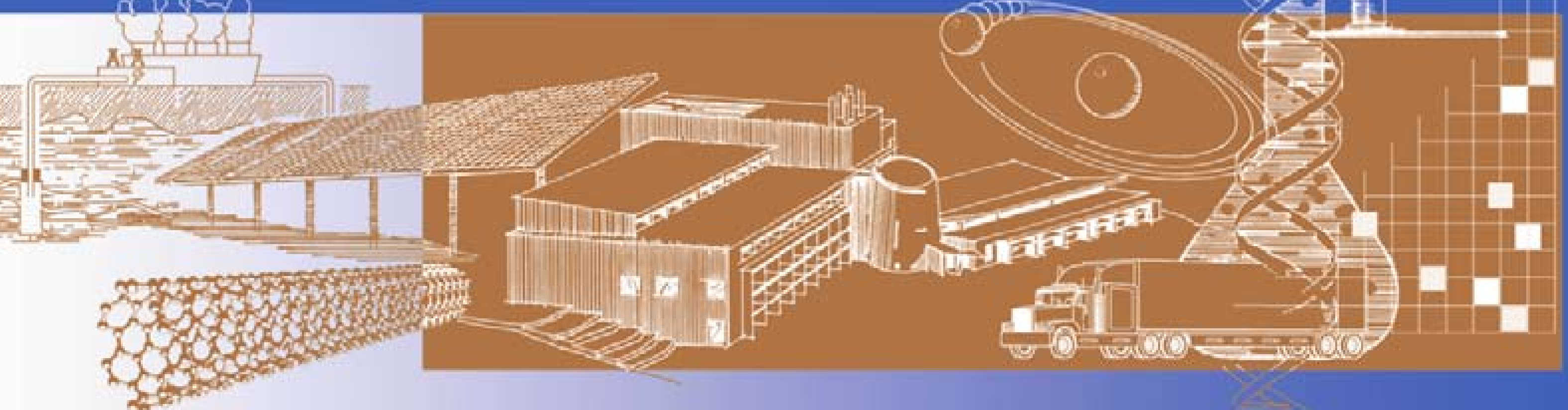

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Systems Integration and the

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Abstract *- The Department Of Energy (DOE) established the Hydrogen Program in response to a Presidential directive. The role of the Hydrogen Program is not to build the nation's hydrogen infrastructure, but instead to develop and validate technologies that will enable industry to make commercialization decisions that lead to establishing and evolving a* national *hydrogen infrastructure. To provide a solid foundation for a mission-driven Program consistent with the President's directive, the DOE asked the National Renewable Energy Laboratory to establish a Systems Integration Office (SIO) and develop an Integrated Baseline that could be used to effectively and efficiently manage the Hydrogen Program. The SIO has employed a structured process, based on hierarchical decomposition, to identify, define, and analyze the requirements and tasks needed to satisfy the Hydrogen Program's mission. The result is an on-line integrated baseline (i.e., both technical and programmatic considerations) that ensures that these mission requirements and all aspects of the President's directive are addressed.*

Keywords: Systems Integration, Integrated Baseline, Hydrogen Program, CORE.

1 Introduction

In the early 1970s, concern over the United States' growing dependence on imported petroleum, coupled with concerns about our deteriorating air quality as a result of emissions from combustion of fossil fuels, prompted the Department of Energy (DOE) to begin investigating hydrogen technology. However, it was not until President Bush's 2003 State of the Union address that significant funding became available.

> *Tonight I am proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles. With a new national commitment our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom so that the first car driven by a child born today could be powered by hydrogen, and pollution free*.[1]

In response to this Presidential directive, the DOE established the *Hydrogen Program* (*Program*) with the following mission:

> *To research, develop, and validate hydrogen production, delivery, storage and fuel cell technologies*.[2]

The *Program* was created to develop and validate technologies that will enable industry to make the commercialization decisions that lead to establishing and evolving a national hydrogen infrastructure based on domestic resources that will reduce the nation's dependence on foreign oil; however, it will be up to industry to build the nation's hydrogen infrastructure. It incorporates the results of past efforts with the direction and guidance of the *National Energy Policy*,[3] the *National Hydrogen Vision*,[4] the *National Hydrogen Energy Roadmap*,[5] the *President's Hydrogen Fuel Initiative*,[6] the *Energy Policy Act of 2005*,[7] the *Advanced Energy Initiative*,[8] the *FreedomCAR and Fuel Partnership*,[9] and the *DOE Strategic Plan*.[10] The *Program* includes activities being conducted by the following DOE program offices: Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy, and Science.

In late 2003 the DOE commissioned the National Academies to review the *Program*. One significant recommendation was to establish an independent systems integration effort to ensure that the various *Program* elements (such as production, delivery, and storage) fit together seamlessly. In response to this recommendation the Systems Integration Office (SIO) was established at the National Renewable Energy Laboratory in Golden, CO.

2 Systems Integration Approach

Shortly thereafter, top-level management began asking, "what's the *Hydrogen Program* going to cost and how will it be effectively managed?" Although the President designated $1.2 billion for the *Program* during the period fiscal year (FY) 2004 through FY 2008, a defensible budget request also needed to be constructed for the period FY 2009 through FY 2015 – the date that enabling technologies will permit a technology readiness decision to be made – and an effective management tool needed to be developed and implemented.

The SIO recommended implementation of a structured process, based on hierarchical decomposition, to identify, define, and analyze the technical tasks needed to satisfy the *Hydrogen Program's* mission – an Integrated Baseline for defining and managing the *Program* in accordance with DOE Order 413.3, *Program* and *Project Management for the Acquisition of Capital Assets*.[11] An approved Integrated Baseline would allow the *Program* management team to:

- Establish a standard approach for organizing the various elements of the *Program;*
- Facilitate the formation of a comprehensive time-phased budget based on thorough schedule planning and cost estimating;
- Measure performance against an approved *Program* baseline

Figure 1 illustrates the SIO's concept for developing such an Integrated Baseline. Beginning with a vision of a future operational hydrogen economy by the year 2040, and recognizing that it would take about 20 years to accomplish once industry began offering significant numbers of hydrogen-powered vehicles approximately five years after a serious commercialization decision was made, a desired level of technological capability to be achieved by the Program by 2015 was established. These 2015 Hydrogen Program targets define the technical baseline that drives the work to be accomplished, the schedule to be met, and the estimated cost – i.e., the programmatic baseline. Together the technical and programmatic baselines comprise the Integrated Baseline and form the basis for a requirements-driven, mission-oriented Program.

The technical portion of the baseline is the complete reference set of technical data describing the current ("as-is") state of technological capability and the desired ("to-be") states at various times in the future. These desired states of technological capability are derived from the vision for an operational hydrogen economy in 2040. In essence, the technical baseline ensures that the *right work* is being done. It is derived from the national policy objectives and other top-level requirements, and is consistent with an assessment of both existing and potential new technology. It defines where the hydrogen technological capabilities are at any point in time and where they ultimately must be to satisfy the future vision.

In operational terms, the programmatic portion of the baseline ensures that the work is being *done right* – i.e., the work that must be accomplished to provide the required technological capabilities. The *right work* will be accomplished according to approved work plans, on time and on budget. The programmatic baseline contains all *Hydrogen Program* data pertaining to the approved scope of work, cost, and schedule.

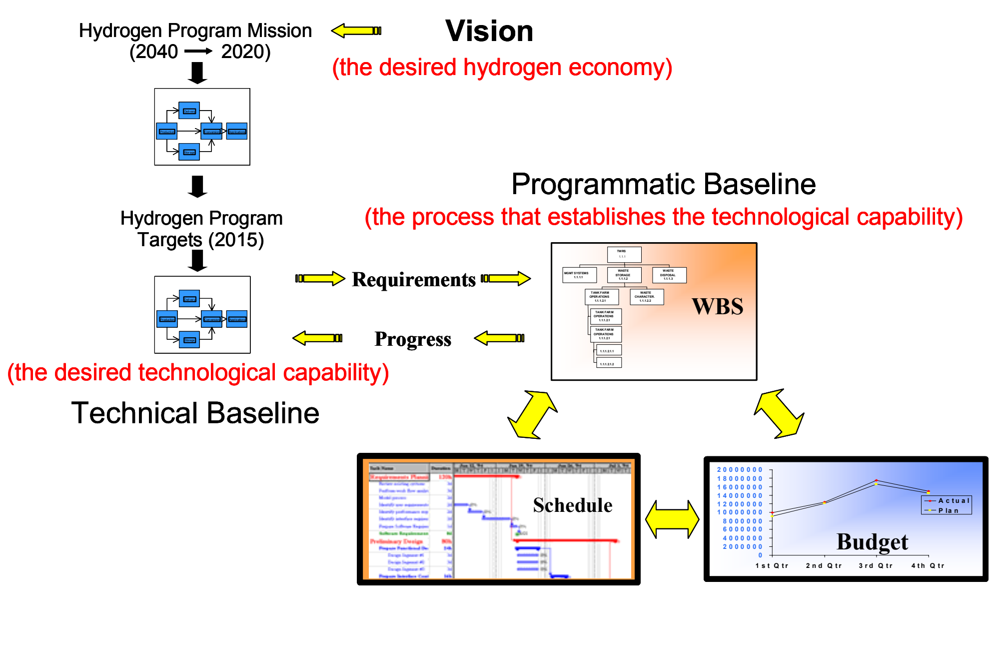

Figure 1. A Requirements-Driven, Mission-Oriented Hydrogen Program

2.1 Challenges

Several significant challenges had to be overcome to develop and implement the Integrated Baseline:

- *Ongoing Program*. The *Hydrogen Program* is comprised of nearly 300 ongoing projects spread across different organizations, addressing a variety of technological disciplines, many of which are on the leading edge of technology. Implementing systems integration within an ongoing program is especially challenging due to the existing mindset of managers and staff, other demands on their time, the "not-invented-here" attitude, and steadfast resistance towards systems engineers probing their activities.

- *Systems Integration within 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.

- *Inherent Uncertainty in R&D*. 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 and getting them accepted by the *Program* staff can be challenging.

2.2 Existing Hydrogen Program Structure

The *Hydrogen Program* was already well underway for several years prior to the SIO getting involved and was striving to satisfy the objectives, targets and milestones in the *Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year Research, Development and Demonstration (MYRD&D) Plan*.[2] Figure 2 shows the "as-is" *Program* structure encountered by the SIO. Requirements appropriately flowed down from top-level policy directives and documents. Barriers had been identified that represented obstacles in satisfying the requirements and became the basis for creating top-level technical tasks which were determined to be necessary to overcome the obstacles. Unfortunately, these top-level tasks were only decomposed into one more level of detail – hardly enough to allow detailed work descriptions, defensible budget estimates, or sufficient definition of the approximately 300 projects being funded by the *Program*.

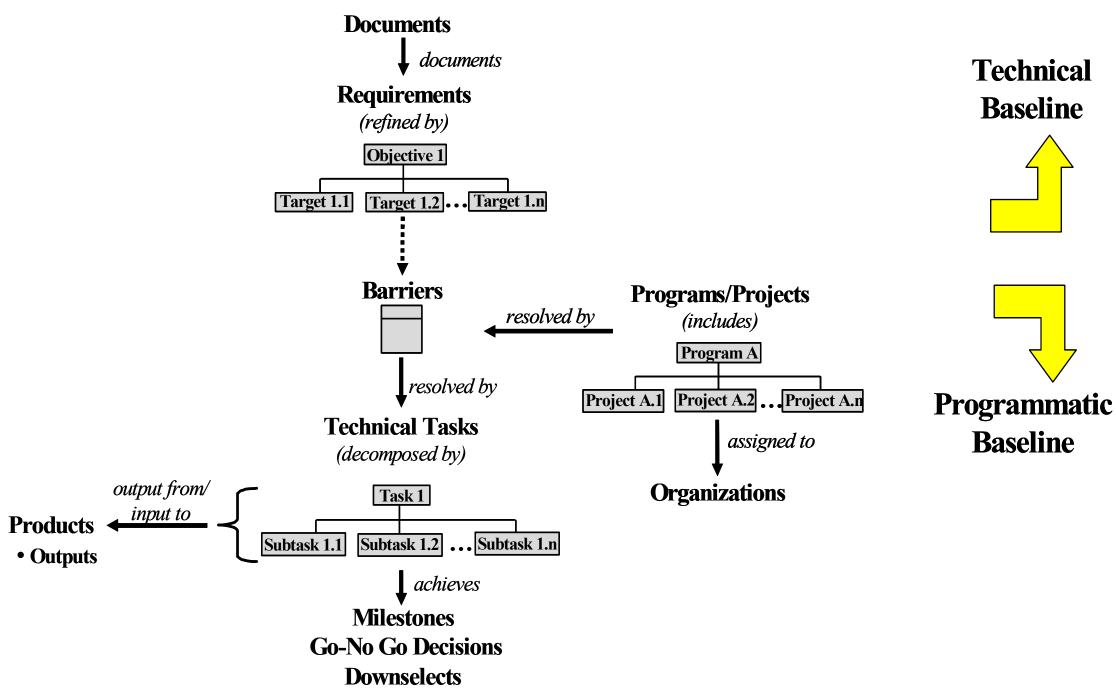

Figure 2. ***Hydrogen Program*** **Structure prior to Systems Integration**

2.3 Integrated Baseline Structure

A top-level work breakdown structure (WBS) had been developed early in the conceptual stage of the *Hydrogen Program* by dividing it into ten distinct Program Elements: production, delivery, storage, fuel cells, technology validation, safety, codes & standards, education, systems analysis, and systems integration. However, it quickly became apparent to the SIO that this level of detail was not sufficient to create detailed budget forecasts, nor manage the overall *Program* effectively. Thus an effort was undertaken to create a more detailed WBS which would be consistent with the size, complexity, and risk of the *Program*, and the Program Manager's need for more effective control. Specifically, the SIO organized working sessions with *Program* staff to develop a more detailed work breakdown structure, master schedule, and defensible cost estimates.

Each Program Element manager was instructed to define, schedule and cost the work necessary to meet all their key targets and milestones. *Program* requirements flowed "top-down", whereas *Program* budgets were established "bottoms-up". Emphasis was on developing a methodology that could be uniformly applied throughout the *Program*, so that a consistent set of budget estimates would be constructed across all Program Elements.

Work Breakdown Structure. The WBS is a task-oriented decomposition of the *Program* and is organized in multiple levels of increasing detail to reflect the complexity of the work scope. Its purpose is to divide the *Program* into manageable segments of work to facilitate program management, cost estimating and budgeting, schedule management, reporting of cost and schedule performance, and cost and schedule control. A well-designed WBS ensures that all required work is incorporated in the *Program* and that no unnecessary work is included. The WBS defines the work scope portion of the programmatic baseline.

Scheduling. The first step in scheduling all WBS tasks and sub-tasks was to specify the dates for all key targets and milestones that would be supported by the (sub-) tasks. The start/stop dates for each lowest level sub-task were selected so that the key targets and milestones would be met on time. This became the *Program's* schedule baseline.

Cost Planning. The purpose of cost planning was to identify the resources needed to accomplish the scope of work and to estimate the associated costs. An unconstrained, bottoms-up approach was used to generate the *Program* cost estimate by preparing cost estimates for all authorized work as defined at each lowest level activity in the WBS. After the initial cost estimates were prepared, the *Program* management team met to evaluate and validate each proposed cost, and to reach a consensus on a final cost profile for the *Program*. Once the cost estimate was approved at all management levels, it became the *Program's* cost baseline.

Figure 3 shows the new expanded structure for managing the *Program* after the implementation of the SIO's process.

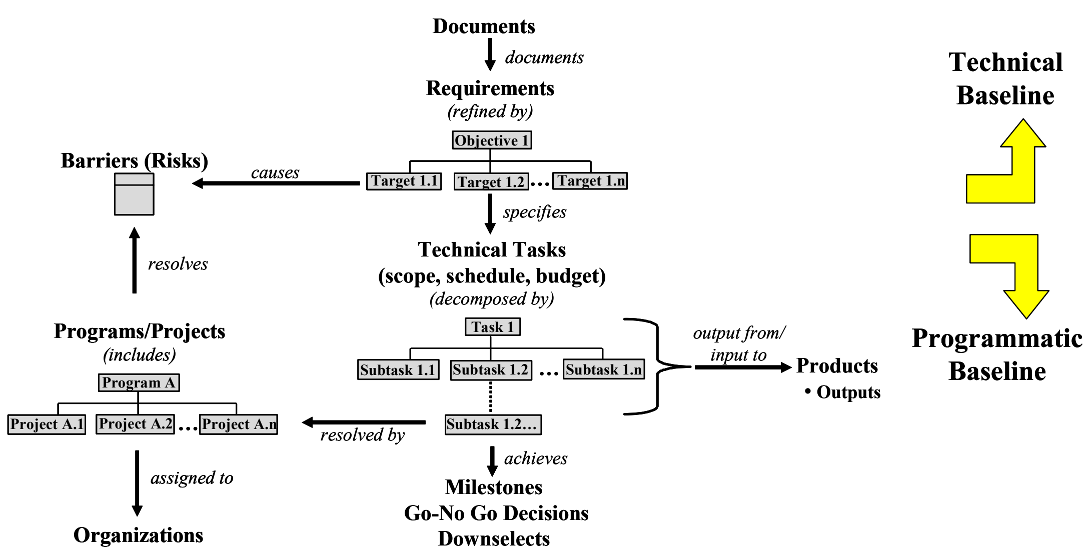

Figure 3. ***Hydrogen Program*** **Structure after Systems Integration Implementation**

Table 1. Partial Example of a WBS Dictionary

WBS Element	Title	Description	Basis of Estimate
Fuel Cells			
1. Develop membranes that meet all technical targets			
1.1 Develop/identify ionomers			
1.1.1	Reduce cost of raw materials	Develop advanced membrane materials that are lower cost than Nafion.	Assumes current level of activity is sufficient to lower membrane costs to achieve the 2010 targets. The level of activity needs to increase as the 2015 commercialization decision approaches.
1.1.2	Improve conductivity over the entire temperature and humidity range	Develop advanced membrane materials that have improved performance, i.e. higher conductivity over the full operating range of temperature and humidity.	Assumes that some membrane material candidates that meet performance over the temperature and humidity range of 2015 targets will be needed in 2012 so that they can be incorporated into an MEA and stack by 2015. Breakthroughs will be needed to meet the lower humidification requirements and will require increased emphasis in 2009 - 2012.
1.1.3	Increase mechanical/ chemical/thermal stability over the entire temperature and humidity range	Develop advanced membrane materials that have the chemical and mechanical strength to operate over the full operating range of temperature and humidity.	Assumes that some chemical, mechanical and thermally stable membrane material candidates with temperature and humidity range of 2015 targets will be needed in 2012 so that they can be incorporated into an MEA and stack by 2015. Breakthroughs will be needed and require increased emphasis in 2009 - 2012.

Table 2. Partial Example of the Estimated Annual Costs by WBS

			Fiscal Year											
Level 0	Level 1	Level 2	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Totals
	HFCIT Program		124,578	121,016	187,802									
		Hydrogen Production	8,680	5,898	22,550									
		Hydrogen Delivery	2,500	1,000	6,600									
		Hydrogen Storage	22,386	26,598	35,213									
		Fuel Cells	55,044	34,054	57,075									
		Technology Validation	26,098	33,594	39,566									
		Safety, Codes & Standards	5,335	11,800	12,500									
		Education	0	1,777	2,000									
		Systems Analysis	2,142	3,220	9,138									
		Systems Integration	2,393	3,075	3,162									

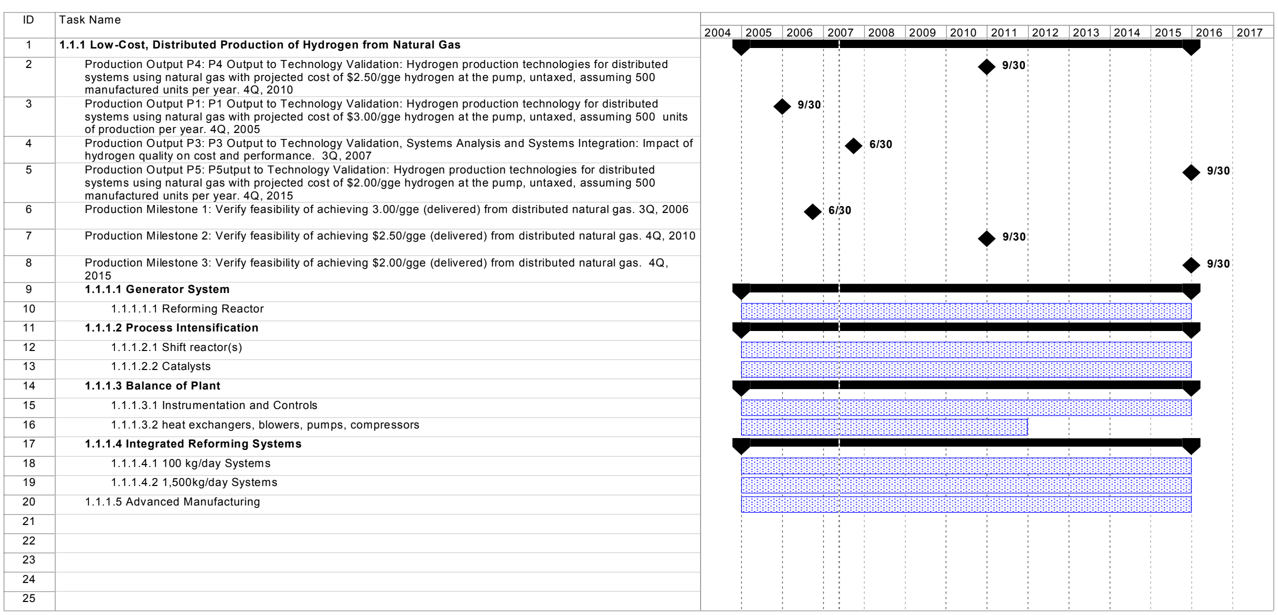

Figure 4. Partial Example of a Gantt Chart

2.4 Implementation in CORE

The SIO's robust approach to program planning ensured that the amount of work to be accomplished, the time allotted to accomplish the *Program* activities, and the resources required to complete the work scope were evenly balanced. CORE, a computer-assisted systems engineering support tool, was used to organize, coordinate, and document the baseline development effort by capturing the complete set of requirements, tasks, milestones, and projects. The CORE model provides the *Hydrogen Program* and its Program Element Managers with the necessary requirements traceability to establish a defensible basis for budget estimates and technical decisions; it also produces a variety of output tables and diagrams, including requirement hierarchies, WBS dictionaries, schedules, and annual cost estimates. Outputs from the CORE model can be made available on-line to all *Hydrogen Program* participants. This will ensure that everyone is working to the same set of requirements at all times. Outputs from the CORE model interact directly with Microsoft Excel and Microsoft Project which is the primary tool for displaying schedules.

WBS Dictionary. CORE can produce WBS Dictionaries (Table 1) consisting of detailed descriptions of each lowest level subtask and the basis-of-estimate for determining its annual cost.

Annual Cost Estimates. CORE can export data from the Integrated Baseline to Microsoft Excel and produce tables containing the annual cost estimates for each *Program* element, task and subtask through FY 2015. Table 2 is a partial example showing cost data only through FY 2007.

Master Schedule. CORE can export data from the Integrated Baseline to Microsoft Excel and Project to produce Gantt charts (Figure 4) consisting of the start/stop dates for every task and subtask, plus their associated milestones.

3 Conclusions

Successful satisfaction of the President's directive and the pace at which the transition to a hydrogen economy must occur has created a complex systems integration challenge for the DOE which is responsible for achieving a level of "technology readiness" that will enable the automobile and energy companies to opt for commercial availability of fuel cell vehicles and hydrogen fuel infrastructure by 2020. To meet this challenge the *Hydrogen Program* is being managed in accordance with an approved Integrated Baseline that captures all of the requirements imposed upon the *Program*, identifies the barriers to satisfying the requirements, the work scope, schedules, and budgets necessary to overcome the barriers, the projects that have been funded to accomplish the work, and the risks that must be managed. Figure 5 illustrates the overall concept.

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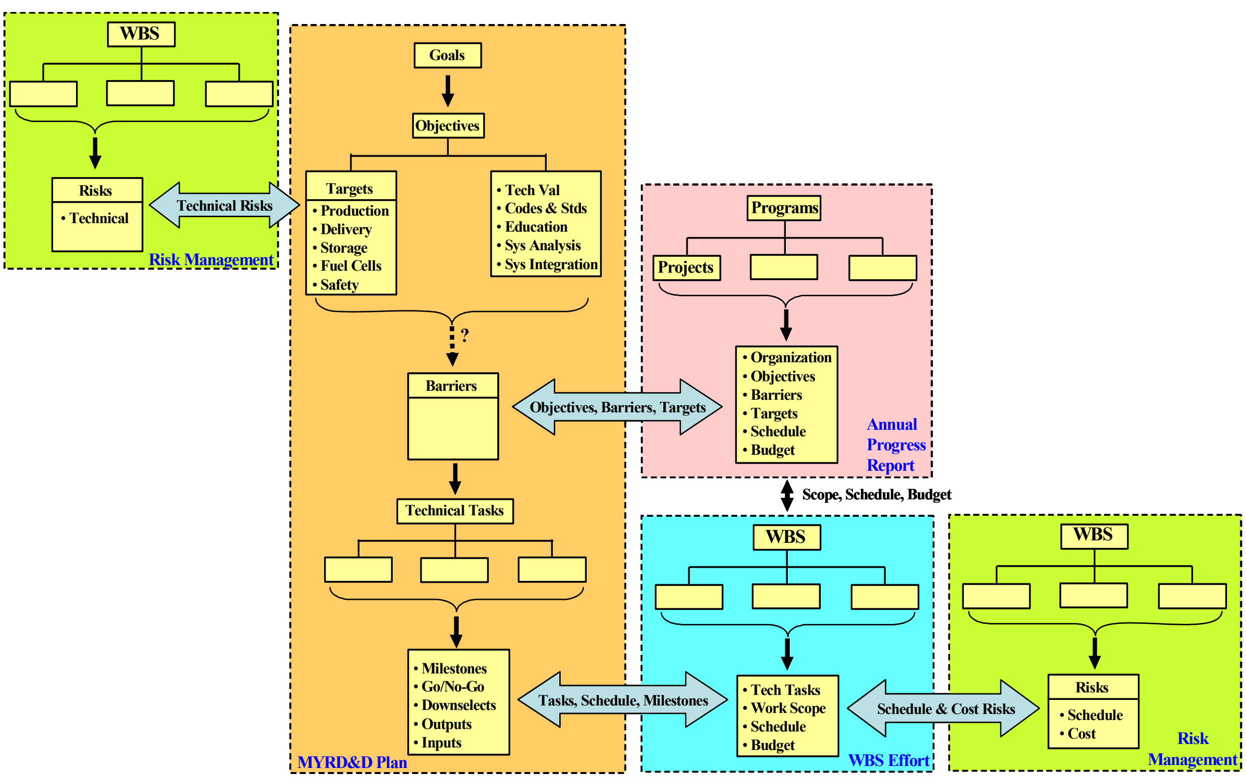

Figure 5. The Integrated Baseline Concept for the Hydrogen Program

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[1] *2003 State of the Union Address*. Washington, D.C., The White House, January 28, 2003

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[11] *Program and Project Management for the Acquisition of Capital Assets,* DOE Order 413.3: Washington, D.C.: U.S. Department of Energy, January 3, 2005

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