The Hydrogen Delivery System

Final Report

Submitted by

The Hydrogen Team

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Executive Summary

We are entering a period of transition for the energy business, where winners for the next 50-100 years will begin to emerge, and the long-term viability of other business will falter. Vehicle fuel prices are rising more rapidly than inflation due to increasing demand, low vehicle fuel efficiency standards and limited cost effective alternatives to petroleum-based fuels. Dependence on foreign nations for oil is an economic and national security issue, leading to record trade deficits and an economic dependence on nations that may wish the U.S. ill-will. Furthermore, the trend in global warming has been linked to green house gases, one of which, carbon dioxide (CO_2) needs to be reduced to reverse this trend.

These factors have combined to shift the regulatory and consumer environments in favor of alternative energy solutions, and against the traditional oil business. Hydrogen fuel represents one of the most promising alternative energy sources, and therefore our team has set out to investigate a potential investment in a Hydrogen Delivery System.

Hydrogen shows the most promise in solving stakeholders' needs:

- Hydrogen is the most available element in the universe, and is contained in many of the hydrocarbon fuels that we use today for energy
- Fuel Cell technology can practically achieve 80% efficiency which is much greater than theoretical efficiencies in current combustion processes[1]
- Hydrogen production systems can be designed to leverage renewable energy resources and energy from nuclear power plants in order to minimize CO_2 and pollutants
- Hydrogen is a potential path for oil companies to diversify their energy delivery portfolio and be less dependent on oil as consumer's transition over to hydrogen fuel cell vehicles.

Given the favorable environment and the availability of low-cost Government financing, now is the time for this Investment Review Board to consider our appropriate Hydrogen strategy, particularly for the delivery system. The Department of Energy has estimated that 70% of the retail cost of Hydrogen will be due to the delivery infrastructure. Our oil company already has an extensive delivery infrastructure for petroleum and an established customer base, providing an advantage over most competitors. Therefore, the focus of our analysis is on the necessary investments to transition the current delivery infrastructure to Hydrogen. This report will consider:

1) A system architecture, to capture the recommended technologies and components that make up the target end state,
2) A detailed investment analysis of where and when to transition stations under varying market conditions, and
3) A financial analysis of the required investments, and likely return.

Our recommendation is to take a two phase approach to implementing a hydrogen delivery system, consisting of an Initial Phase and a Step-Out Phase. During the Initial Phase of the System, hydrogen production occurs at a large facility, is delivered by truck to a terminal facility and distributed via truck to the fuel station. During the Step-Out Phase, additional hydrogen production will be co-located at the terminal facility and delivered via truck or pipeline to the fuel station. The Initial Phase requires partnering with a hydrogen provider in order to share risk and maximize use of current infrastructure to minimize upfront costs while market adoption of Hydrogen Fuel Cell Vehicles (H_2 FCV) is low (< 1%). As market adoption rates for H_2 FCV's and consumer demand for hydrogen increases, production will be moved to the terminal facility in order to flatten the distribution

[1] "Fuel Cells", World Energy Council, http://www.worldenergy.org/focus/fuel_cells/377.asp

network, allowing the delivery system to scale cost effectively to higher demand volumes. This Step-Out Phase will necessitate construction of hydrogen production facilities at the terminal and require that a second investment decision to be made. Furthermore, the company will need to revisit the partnering arrangement made with the producer during the Initial Phase; we will need to continue the partnership with the producer, purchase the producer or take on the responsibility of production.

We performed an extensive technical evaluation of hydrogen technologies related to delivery states of hydrogen and the storage and dispensing of hydrogen. We anticipate that H_2 FCV's will store pure hydrogen gas in solid materials such as metal hydrides or in compressed gas form, requiring the architecture to support a delivery state of pure compressed hydrogen gas. Our analysis to support the Initial Phase architecture and this technical approach can be found in Sections 2 and 3.

In Section 4, our analysis of where and when to transition stations shows a moderate degree of variability in these decisions depending on market conditions of adoption rate, expected retail price, and available technologies for delivery. However, useful conclusions can be drawn about locations that will require stations in most scenarios, providing early input to ensure the company has strategically located retail outlets in these locations in advance of a transition. Furthermore, the model will have continued utility for annual planning as we are able to establish more certainty in these market conditions.

Given the recommended architecture and the analysis of where and when to transition stations, we conclude with a financial analysis of the viability of this investment in Section 5. We are able to conclude that the investment would represent a positive net present value 97.5% of the time. Meaning the cumulative probability distribution of the Net Present Value (NPV) indicates that the probability of a negative NPV to be less than or equal to 2.5%. The largest influence on the likely return is the likely retail price for H_2, which we set based on projections for retail gasoline prices. Our ability to shape or control this factor through regulation, partnerships, or our oil business unit will have the largest impact the likely success of this investment.

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1 Introduction

1.1 Background

The Hydrogen Team developed and adopted the following development methodology for this project as illustrated in Figure 1.

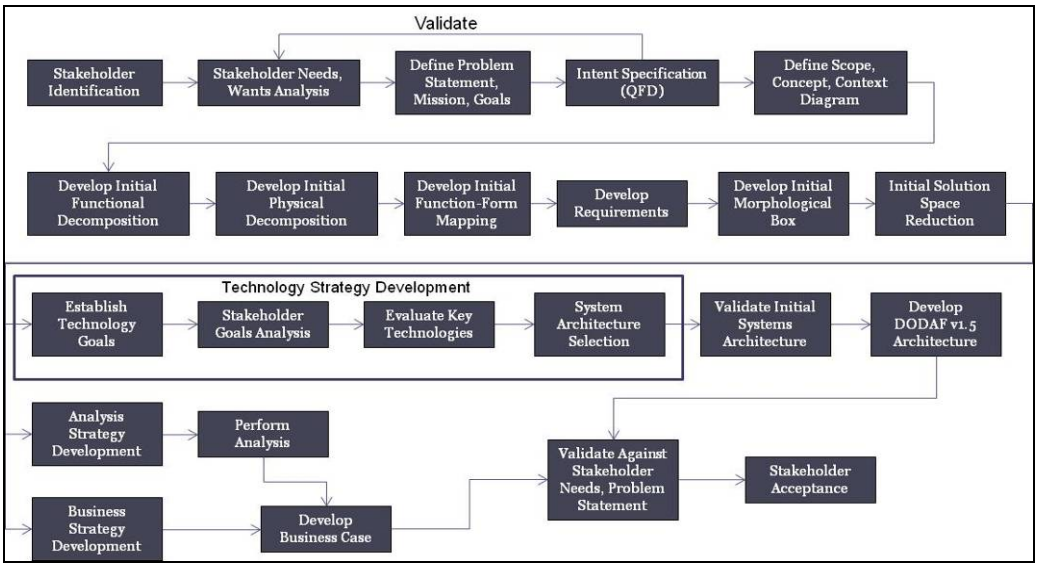

Figure 1. Project Development Process (PDP)

1.2 Team Role and Responsibilities

The Hydrogen Team is taking on the role of an oil company that is looking to add Hydrogen Energy to the company product portfolio and establish a supply chain for distribution of Hydrogen for consumer Fuel Cell Vehicles (FCVs), similar to current vehicle fuel distribution system:

The Hydrogen Team will perform analysis in this oil company role in order to support a business case and investment strategy.

The Hydrogen Team will develop a business / technology strategy and architecture to:

- Determine Risks, Requirements, Refine Goals
- Drive investments in technology areas in order to meet target goals
- Drive organizational decisions on investment via a business case

1.3 Project Intent, Expected Results

The Hydrogen Team will develop an architecture for delivery of Hydrogen to the marketplace and develop a business case and investment strategy that makes the case for deploying this Hydrogen Delivery System. The expected result is a completed architecture and viable business case (less than 5% negative NPV) for a hydrogen delivery business for the Fairfax County region which may be expanded to a nationwide deployment.

2 Problem Definition

2.1 Stakeholder and Needs Identification

The Hydrogen Team identified stakeholders and needs using a creative Delphi process, where team members identified stakeholders with requisite needs in preparation for a group meeting. The output of that effort is illustrated in Figure 2.

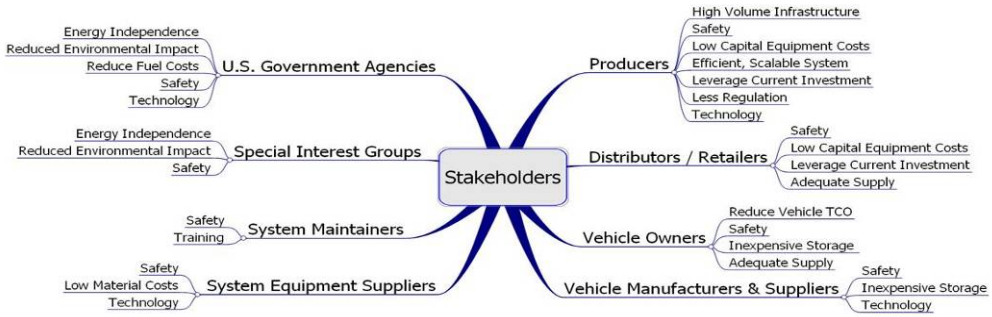

Figure 2. Stakeholder & Needs Identification

The Hydrogen Team identified the following stakeholders: Vehicle Owners, Government Regulation, Government Policy Makers, Environmental Interest Groups, Producers, Distributors, Fuel Station (Forecourt) Operators, Vehicle Manufacturers and Equipment Manufacturers.

2.2 Stakeholder Needs Analysis and Value Map

The Hydrogen Team evaluated the importance of stakeholder needs versus the stakeholders identified by analyzing stakeholder needs versus underlying issues and then determined the impact (mostly business, economic - cost, risk, time, revenue) of those issues and proposed actions to remediate the issue (which was used later in forward definition of specification in QFD). The Hydrogen Team ranked stakeholder needs using a relative weighting based on rank ordering and calculated the needs score from relative weights and rank order. The output of that exercise is below in Figure 3.

Stakeholder Needs Analysis

		Column #	1	2	3	4	6	7	8	9	10		
		Relative Weight (Order Ranking, Highest = Best)	1	0.8696	0.8478	0.6739	0.5435	0.5435	0.3478	0.1957	0.1957		
Row #	Relative Weight (Order Ranking, Highest = Best)	Stakeholder Needs \ Relevant Stakeholders	Producer	Distributor	Government Policy	Retailer	Vehicle Owner	Government Regulation	Equipment Manufacturer	Environmental Interest Groups	Vehicle Manufacture		Needs Score
1	1	Safety in the storage, transport and use of fuels	3	5	4	2	4	5	0	4	2		1
2	0.69	High volume hydrogen distribution system	5	5	3	4	0	0	3	0	0		0.594
3	0.724	Inexpensive Storage, Compression methods and technologies. Low Cost Transport.	4	5	2	4	0	1	3	0	2		0.587
4	0.69	Adequate Supply	4	3	4	4	4	1	0	0	0		0.586
5	0.69	Hydrogen as a Low Cost Fuel Alternative	4	2	4	4	5	1	0	0	0		0.573
6	0.621	Less regulation and / or systems and delivery methods	3	4	3	3	0	5	0	0	0		0.471
7	0.621	Leverage current investments (capital equipment, infrastructure, processes, technology)	3	5	3	3	0	1	3	0	0		0.462
8	0.552	Efficient, scalable process	5	5	3	3	0	0	0	0	0		0.423
9	0.586	Low capital equipment costs for system components	5	3	0	4	0	0	5	0	0		0.389
10	0.655	Reduced Environmental Impact of Vehicles, System	0	0	4	0	4	4	1	5	1		0.334
11	0.483	Safety in production	5	0	4	0	0	5	0	0	0		0.295
12	0.345	U.S. Energy Resilience	0	0	4	0	3	1	1	0	1		0.116
13	0.276	High Volume, High Revenue, Low Cost Production	5	3	0	0	0	0	0	0	0		0.116
14	0.345	Reduce Total Cost of Ownership (TCO) of vehicle	0	0	1	0	5	1	0	0	3		0.089

Need Ranking	
0	Not used
1	Not useful
2	Useful to some extent
3	Satisfactory
4	Good
5	Excellent

Figure 3. Stakeholder Needs Analysis

The needs score was calculated from relative weights and rank order. Relative weighting of the stakeholders is the sum of the column scores (total score) divided by the max score out of all of the stakeholders (Producer).

Relative weighting of the Stakeholder needs is the sum of the row scores divided by the max score of all of the needs (Safety in the storage, transport and use of fuels. The "Needs Score" is the sum of (each row score * "Stakeholder Relative Weighting" * "Stakeholder Need Relative Weighting").

Rank ordering of Needs Scores followed Stakeholder Needs relative weighting in most cases. Vehicle manufacturers were the lowest ranked stakeholder for our system. Subsequent Goals Analysis (for more information on the Stakeholder Goals Analysis, refer to Appendix A.6: Stakeholder Goals Analysis) performed by The Hydrogen Team ranked Vehicle Manufacturers near the top since the storage that vehicle manufacturers pick will greatly influence the delivery state of the hydrogen and design of system. System safety, system component costs, and available supply were the highest scoring needs. Environmental concerns, vehicle TCO, production costs were of a lesser concern. This makes sense, primarily since these needs apply more to external systems such as production systems and vehicle systems, where the impact to the environment and customer costs are much greater. We care about these needs but from a system scope perspective, have less control over them, and impact to them.

2.3 Quality Function Deployment (QFD)

After prioritizing needs, The Hydrogen Team mapped the needs to system characteristics. These characteristics represent the forward definition of specifications based on values from stakeholder "wants and needs" and were defined to address the underlying issue(s) defined during value mapping process. Next The Hydrogen Team identified relationships between stakeholder needs and characteristics and evaluated specifications based on the relationships with stakeholder wants and needs. The result is the completed QFD in Appendix A.1: Quality Function Deployment (QFD). The QFD contains a prioritized set of system characteristics mapped to stakeholder needs.

The analysis identified needs and their relationships to system characteristics. For example:

- Need: Low capital equipment cost, Specification: create a modular system and use parts of existing infrastructure
- Need: Hydrogen as a low cost fuel alternative, Specification: System relies on domestic production

Correlations were identified between Specifications. Negative correlations revealed specifications that may conflict, for example: Low cost and complies with regulations. Positive correlations were identified which were related and may overlap.

2.4 Problem Definition, Mission and Goals

Problem Statement: Cost effective and feasible methods to deliver hydrogen to consumers for use in automobiles do not exist.

Mission: Develop a feasible architecture and investment strategy for a hydrogen distribution system for anticipated usage between 2015 - 2025.

Goals for Hydrogen Delivery:

- By 2017, Cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units <$1.00 *per kg of hydrogen in total or $0.01 / mile @ a Hydrogen Fuel Cell Vehicle mileage of 100 miles / gallon of gasoline equivalent (gge).*[2] It is expected that the overall delivery costs will be the largest cost contributor to the hydrogen retail cost.
- By 2017, Carrier System Energy Efficiency (H_2 Out / (H_2 In + Expended Energy)) of 85% from production to dispensing[3]

[2] "Hydrogen Delivery Technology Roadmap", pp. 53 - 56, http://www1.eere.energy.gov/hydrogenandfuelcells/delivery/pdfs/delivery_roadmap0207.pdf

[3] "2007 Technical Plan - Delivery", pg. 3.2-1, http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/delivery.pdf

3 Systems Engineering Methodology

3.1 Scope and Context Definition

Figure 4 is the p-Diagram for the system. Key inputs and outputs to the Hydrogen Delivery System are Hydrogen Energy and transactional requests related to deliveries and schedules. Most key "Uncontrollables" are a part of the environment such as energy demand / supply, unanticipated technology, events that impact the supply chain, regulations and laws, technologies used in the end user vehicle and the business strategic and operational goals. Key "Controllables" relate to internal systems, sites / facilities that we have control over.

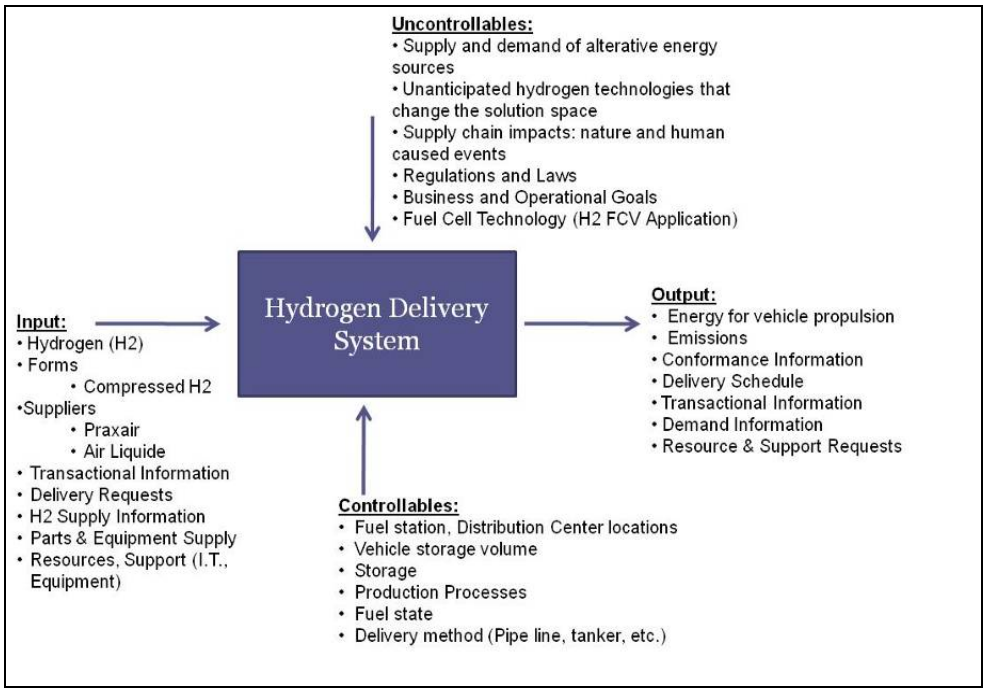

Figure 4. Hydrogen Delivery System p-Diagram

3.2 Operational Concept

The operational concept covers primarily two scenarios or use cases:

1. Centralized Distribution: Hydrogen Energy Product is transported from a producer to a terminal, then transported from a terminal to a retail fuel station
2. Hybrid Distribution: Hydrogen Energy product, produced at the terminal is transported directly to the retail fuel station

The operation concept diagram in Figure 5 embodies the operational architecture and scenarios supported by the Hydrogen Team's business and technology strategies and will meet the needs of the stakeholders based on previous needs analysis.

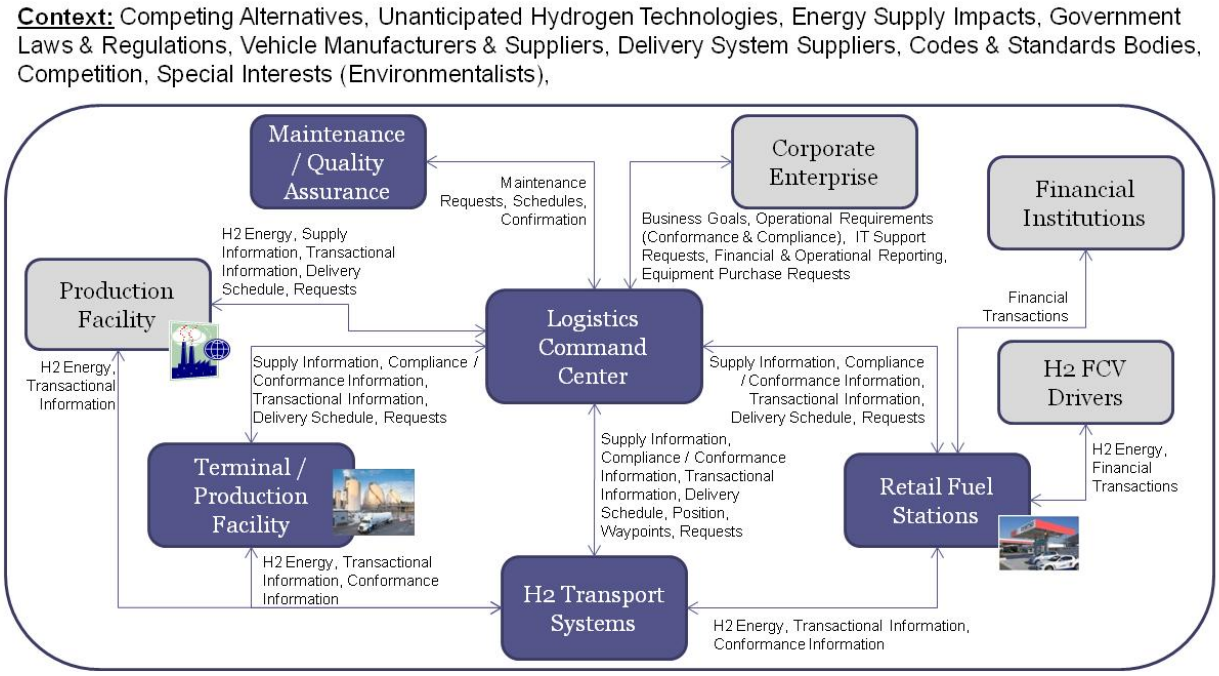

Figure 5. Operational Concept / Context Diagram

3.3 Functional and Physical Decomposition

Initial Functional and Physical Decompositions were derived from the Quality Characteristics and Stakeholder Needs in the QFD and the Operational Concept / Context were input into and maintained with Core v5.0, an architecture development tool developed and provided by Vitech Corporation under academic licensing.

The latest functional and physical component decompositions are contained within Appendix A.2: Functional and Physical Decomposition.

3.4 Intent Specification

The intent specification consists of the QFD, function-form mapping, requirements, standards, codes, and regulations.

3.4.1 Function-Form Mapping

The function-mapping for the system, is currently maintained within Core v5.0 and can be found within Appendix A.3: Function-Form Mapping.

3.4.2 Requirements, Codes, Standards and Regulations

Requirements, Codes, Standards, and Regulations (located in Appendix A.4: Requirements, Codes, Standards and Regulations) were determined based on characteristic requirements from the QFD (Figure 23 located in Appendix A.1: Quality Function Deployment (QFD)), Goals Analysis (performed during the formulation of the Technology Strategy), and research of current agencies and organizations. The characteristic requirements were derived from the system characteristics defined in the QFD. Performance requirements were derived from the Goals (see Table 9). Functional requirements were derived from the functional architecture.

High-level functional requirements for the system were developed based on the functional decomposition and operational concept diagram. Updated Requirements, Codes, Standards and Regulations are available in Appendix A.4: Requirements, Codes, Standards and Regulations.

The Hydrogen Team further decomposed the functions, forms, goals and requirements as a part of the DoDAF v1.5 architecture development process and methodology described later in this document in Appendix B: DoDAF v1.5 Architecture Framework Process Artifacts.

3.5 Technology Strategy

3.5.1 Technology Goals

Goals were derived from the goals established by the Department of Energy or derived from characteristic requirements in the QFD (see in Table 9 in Appendix A.4: Requirements, Codes, Standards and Regulations).

These key goals and targets were used in the Architecture Selection Process to evaluate and grade key technologies and to decide if and when technologies can be employed.

3.5.2 Architecture Selection Process

The Hydrogen Team established the Solution Space by developing a Morphological Box of alternatives based on the function-form mapping of architecture alternatives developed earlier. These alternatives focus on four key attributes of the Hydrogen Delivery System to the operational system: Vehicle Application, Distribution State, Delivery Method, and Distribution Model. Vehicle Application is the state of Hydrogen as it is dispensed and stored in the vehicle: Compressed Hydrogen, Liquefied Hydrogen, Liquid Carrier, Solid Carrier and Gaseous Carrier. Distribution state of the Hydrogen Energy is represents the state by which Hydrogen will enter the system. This amounts to 200 combinations of system solutions possible (only picking one solution from each category) by multiplying 4 x 5 x 2 x 5 = 200

Vehicle Application	Distribution State	Delivery Method	Distribution Model
Compressed Hydrogen	Compressed Hydrogen	Pipeline	Centralized Production (No Distribution Centers)
Liquid Carrier	Liquefied Hydrogen	Vehicle Transport	Centralized Production (1-Tier Distribution)
Solid Carrier	Liquid Carrier		Distributed Production (Fuel Station)
Gaseous Carrier	Solid Carrier		Distributed Production (Home)
	Gaseous Carrier		Centralized Production (n-Tier Distribution)

Figure 6. Morphological Box of Solution Space

We established head-to-head comparative matchups to reduce the number of solutions based on superiority of choices to eliminate characteristics/attributes in **Error! Reference source not found.**.

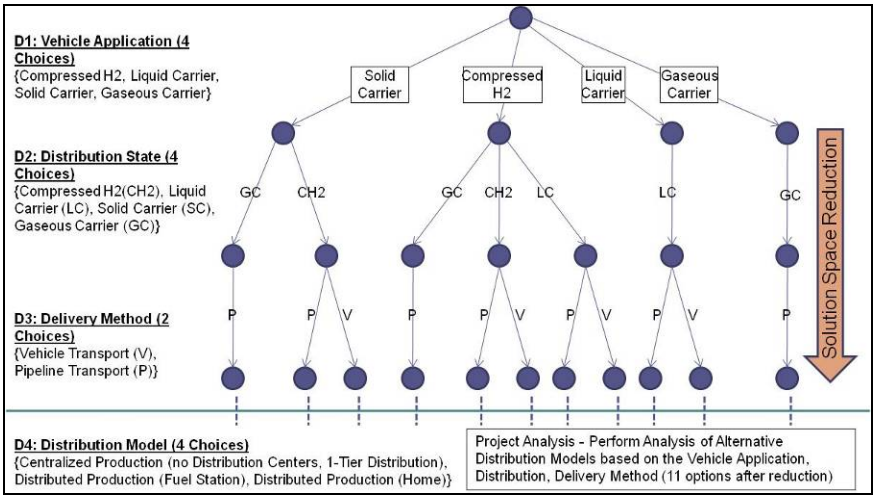

Figure 7. Decision Tree Solution Space Reduction (1st pass)

The Hydrogen Team used a Decision Tree Analysis (see Figure 7) to reduce the number of solutions based on choices starting with the vehicle application, distribution state then delivery method. Solid Carriers as a delivery pathway were eliminated due to cost of the material and feasibility of the process to recover hydrogen. Delivery states of a Solid Carrier for Vehicle Applications such as Solid Carrier hydrogen fuel tanks did not make sense anywhere in the delivery the supply chain, due to loss of Hydrogen, low cycle-life for reversible solid hydride materials and high cost per hydrogen stored of these materials. For Liquid Carriers and Gaseous Carrier delivery pathways, it made sense to keep the hydrogen in this distribution state in order to avoid additional processing / conversions where there would be unnecessary loss of energy.

We established a set of technology goals in order to further evaluate and grade solutions alternatives. We employed goals analysis (for more information on the Stakeholder Goals Analysis, refer to Appendix A.6: Stakeholder Goals Analysis) by rank ordering goals using a similar process to the stakeholder analysis:

1. We isolated goals specific to a Hydrogen Delivery System which links back to Stakeholder Needs and System Characteristics identified earlier:
    - The DOE has developed and refined goals and targets for many of the high-level stakeholder needs that we have identified.
    - We derived Additional goals from other needs not identified by the DOE
2. Though needs were scored by our project during earlier analysis, we needed to go through a second scoring exercise in order to rank order the goals for later architecture alternative analysis.
3. The final score was validated against earlier results from the Stakeholder Needs Analysis

We drew the following conclusions from Goals Analysis:

- Safety, Toxicity, Availability, Efficiency and Cost are the top goals for the system
- Cycle-Life, Energy Density and Weight are the lowest scoring goals
- It is not a surprise that Government Policy Makers are the highest ranked stakeholder, since many of these goals were introduced by Government Organizations, such as the DOE, DOT
- As expected, Vehicle Manufacturers moved up to 2nd since the distribution state and goals directly impact their system versus many of the other stakeholders. As a result, architecture alternatives analysis and development requires close participation with these stakeholders.

- Government Regulations and Environmentalists fall down the list. Though, the impact of regulation is felt in terms of constraints (limits for tube trailers (DOT), pipeline infrastructure)

The result of Goals Analysis was to establish a set of prioritized or ranked goals and ranked stakeholders as an input to architecture selection process. First, we used the ranking of the stakeholders by goal to focus on key alternatives that must be evaluated and selected. Later, we used the goal scores from this analysis to weight the scoring of the key technologies in the Architecture Alternatives Analysis in Figure 8.

Architecture Alternatives Analysis

	Column #	1	2	3	4	6	7	8	9		
	Raw Score (Highest = Best)	27.96	24.9	23.29	23.94	27.29	27.31	27.37	26.75		
		Vehicle Application				H2 Transport					
Row #	Stakeholder Goals / Architecture Alternatives	Solid Carrier (< 2,000 psi)	Compressed H2 (@ 5K psi)	Compressed H2 (@ 10K psi)	Liquid Carrier	Compressed H2 (@ 2640 psi)	Compressed H2 (@ 5K psi)	Compressed H2 (@ 10K psi)	Liquid Carrier		Goals Score
1	Factor of Safety	5	4	3	5	5	4	3	5		1
2	Factor of Toxicity of Fuels, Byproducts, Materials	5	5	5	3	5	5	5	3		0.819
3	System Availability	3	3	3	3	3	3	3	3		0.779
4	Efficiency (% H2 Energy Conserved)	5	5	4	4	5	4	4	4		0.736
5	H2 Cost ($ / Kg H2 or $ / GGE)	0	0	0	0	3	4	5	1		0.683
6	Green House Gas Emissions (ppm)	0	0	0	0	0	0	0	0		0.534
7	Pollutants (ppm)	0	0	0	0	0	0	0	0		0.534
8	Volumetric Density (Kg / L)	5	2	3	5	1	2	3	5		0.529
9	Storage Capacity (Kg of H2 Total)	5	2	3	5	1	2	3	5		0.522
10	Delivery System Capacity (Kg H2 / day)	0	0	0	0	1	2	4	5		0.473
11	System Capital Cost	3	4	3	2	3	4	3	2		0.468
12	Refueling Rate (Kg of H2 / Min)	3	5	5	5	5	4	3	5		0.403
13	System Maintenance Cost	4	4	3	1	5	4	3	1		0.367
14	Technical Readiness Level	4	5	4	1	5	3	1	1		0.296
15	% of H2 by Weight	3	2	2	3	3	4	4	2		0.236
16	Energy Density (KWH / L)	5	2	3	5	1	2	3	5		0.21
16	Cycle Life (Cycles 1/4 tank to full)	3	5	5	3	5	5	5	3		0.191
	System Score	1.00	0.89	0.83	0.86	1.00	1.00	1.00	0.98		

Relative Goal Ranking	
0	N/A
1	Poor
2	Fair
3	Satisfactory
4	Good
5	Excellent

Figure 8. Architecture Alternatives Analysis

As a result of research and analysis on key distribution state technologies, the Hydrogen Team made decisions which affected the solution space. Based on the goals analysis and technology evaluation, we evaluated the key alternatives and selected a system. In selecting a system, we isolated two key components that impact the architecture as a whole through their choice (Vehicle Application of Storage and H_2 Transport Storage). We leveraged both the Stakeholder Needs Analysis and Goal Analysis methods to come up with the method of rank ordering the two alternatives. Goal scores were brought forward in order to properly weight the importance of the goal against the relative ranking score (Goal Score * Relative Ranking). These scores were added to obtain a Raw Score which was normalized to a value between "0" (Worst) and "1" (Best). In areas where the goal did not directly apply, a "0" was score for all of the alternatives in that category.

3.5.3 Architecture Selection

The Hydrogen Team selected the following system solutions as a part of the architecture selection process and architecture alternatives analysis.

Hydrogen FCV Vehicle Storage: (Solid Storage)

Solid Storage is the dominant solution for Hydrogen Fuel Cell vehicles due to the ability of solid carriers such as metal hydrides to store large amounts of H_2 in much smaller places then traditional compression techniques and do so at much lower compression levels (< 2000 pounds per square inch (psi)), which should result in higher efficiency dispensing and lower maintenance costs. Picking Solid Storage over Liquid Carrier Storage eliminates the possibility that a Liquid Carrier will be used in the system.

H_2 Transport: (10 K psi tube trailer (when and if approved by DOT))

The score was close between all four of the transport options being considered. 10 K psi transport storage offers the best capacities for Compressed H_2 and is the only solution that comes close to meeting the average expected daily usage at a retail site by DOE (1500 Kg). However, the DOT has a limit of 2640 psi on all large compressed vehicle payloads. As a result, we will use 2640 psi tube trailers and continue to develop 5K and 10 K psi tube trailers with the expectation that the 5K or both may be approved for use by DOT. We may also reconsider the use of Liquid H_2 for Transmission from Producer to Terminal at distances where it may be advantageous to do so (to be determined by analysis but likely greater than approximately 100 to 200 miles).

3.6 Architecture Development

The Hydrogen Team developed architectures of the Hydrogen Delivery System using the Department of Defense Architecture Framework (DoDAF) version v1.5 and the DoDAF Development Process. For more information on the Architecture Development Process followed, see Appendix B: DoDAF v1.5 Architecture Framework Process Artifacts.

4 Investment Program

In advance of the Business Strategy, the team conducted a detailed analysis of the delivery infrastructure, as the DOE estimates the cost of the delivery infrastructure to be ~70% of the retail cost.[4] Building out the delivery infrastructure involves a complex set of decisions relating to the interaction of demand from many locations, and the timing of investments given various scenarios. This section explains this detailed analysis, and shows that we can expected a positive NPV for a transition effort with moderate price and demand assumptions, using the 10k psi trailer.

4.1 Problem Selection

The DOE estimates the cost of the delivery infrastructure to be ~70% of the retail cost. We therefore focused our analysis is on the ability of our proposed architecture to meet these cost targets. The primary driver of the delivery infrastructure cost is the capital cost to build out or transition various stations. Further, the proper strategy for an oil company is to leverage the existing station infrastructure, investing only in transitioning stations (or tank/pump pairs at a station) to deliver H_2 instead of gasoline. Therefore, this analysis will determine what capital investments are required to transition stations, at what times. The analysis will also indicate which stations should be transitioned for given adoption rates (demand profiles). Figure 9 shows the context for this analysis.

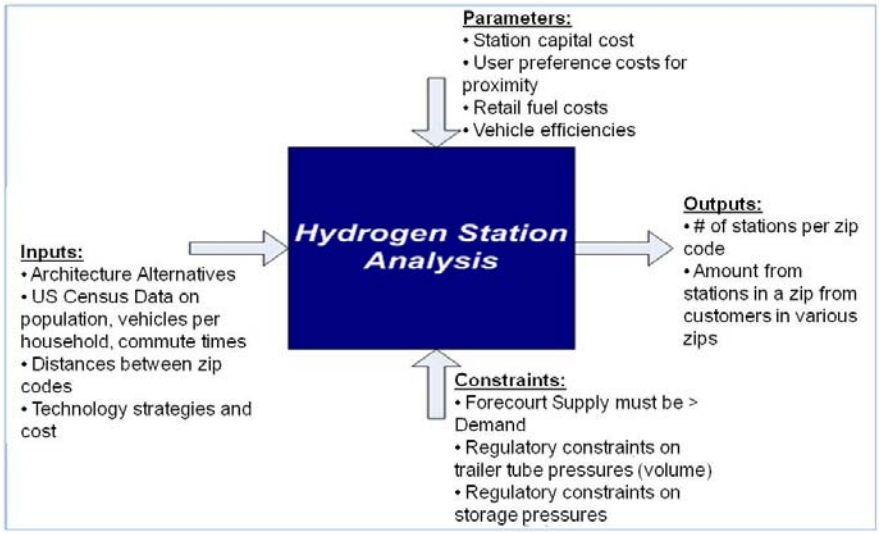

Figure 9. Station Location Analysis Overview

The problem for our analysis is therefore: Given an existing base of fuel stations and a few production facilities located outside the metro area, how many stations should be converted to H_2?

4.2 Methodology & Approach

This model initially focuses only on Fairfax County, Virginia to keep the model within the constraints of available data and academic license restrictions of the modeling software. Further, Fairfax household income indicates that this might be a high area of early adoption, and so is a good area for initial focus. The largest portion of the supply network (the retail stations) will be built out in metropolitan areas, and so this makes sense as an early area of focus. Future phases of this effort should consider migrating the model to a min-cost network flow by making all parameters integral, which should improve performance significantly to allow scaling up to larger analyses once the expense to acquire additional data is justified.

[4] H2A Component Model, H2A Scenario Model, developed and maintained by the DOE, http://www.hydrogen.energy.gov/h2a_delivery.html

Our overall approach is to model this problem as a mixed integer and linear program (MILP) to optimize the location of the stations, determining the minimum number of stations required to satisfy the demand at max profit (negative min cost). The program will also determine in which year the particular stations should be transitioned. The formulation can be found in Appendix C: Station Location Analysis. The specific steps taken were:

1. Identify all the zips in a representative metro area
2. Define the distance between each zip (using zip-code radius finder).
3. Develop the cost (Cij) matrix. Assign a percentage demand function that estimates the likelihood that a customer with demand from one zip code will be willing to purchase hydrogen in another. We assume a max distance that customers are willing to travel is 5 miles. We also assume that customer preference is inversely proportional to the travel cost and the travel time. Both are functions of distance, and so we model the likelihood as an inverse quadratic function.
4. Determine the demand Dj. Use commute time from the US Census as a proxy for demand, and come up with a factor based on vehicle efficiency and a rough translation of commute time to mileage to estimate the amount of "gallons" of H_2 consumed per period. Apply an assumption about the adoption level of H_2 vehicles in the population.
5. Solve the MILP and validate the model. This model was reviewed with Dr. Loerch of the OR faculty.
6. Solve the dual and perform sensitivity analysis.
7. Consider several scenarios with different adoption levels

At present, the analysis determines coverage by proximity: any zip code within 5 miles will be considered "accessible." Future improvements can add accessible nodes around major transit routes even if beyond 5 miles, and can remove zip codes if the company does not have, or cannot build, stations in that area. However, this data was not readily available for the timeframes and budget of this initial analysis.

The model also considers each ***k*** years of the investment horizon. Each annual instantiation is linked to prior years in the sense that any station that exists in the prior year would exist in the future, but would otherwise follow the same model. Costs are all the same, except that they would be modified by the discount rate, and they would reflect a different period until the end of the investment horizon. Details of our cost analysis are included in Appendix C: Station Location Analysis.

4.3 Assumptions

The formulation described assumes constant demand throughout the year. Though seasonal demand is normal and surge capacity is often required, the model will consider this by setting station capacity at 70% of actual capacity, to account for surge factors currently in use today at traditional gas stations.

The current assumption is that all stations offer the same capacity. Really, the term "station" was used for simplicity and ease of understanding: in actuality, we are estimating the number of tanks at a station to convert to H_2. Once the analysis determines the number of tanks to convert to H_2, it is a fairly simple analysis to determine whether those tanks should be multiple tanks within in one or several stations within that zip code.

It should also be noted that the technology strategy considered the possibility of technology advances that might change (increase) station tank capacity. The capacity used in the analysis is the one recommended in the architecture. However, if technology evolves faster than predicted, the analysis can be revisited by changing the capacity parameter.

The formulation currently assumes that customers will demand only from stations near their home. This assumption is merely one of convenience for data gathering – available data (primarily from the US Census) is focused on households (location, income, driving habits). Future improvements could easily be made if more

data is available on employment or driving patterns, so that major commuter centers or major transit routes are added as accessible locations. This would not require a change to the algorithm, but only an addition of accessible zip codes to the Boolean matrix in the set covering portion of the problem.

The model also assumes that customers will choose equally among any accessible station, without preference for those that are closer or easier to access. This is clearly not a valid assumption, but upon reflection, it has little impact on the goals of this project. The model will still predict the capacity (in terms of # of tanks and stations) required in each zip code, and we will assume that a future analysis of more granular data (or even just the expertise of knowledgeable regional managers) will be able to appropriately locate stations within accessible zip codes.

The model does not explicitly consider competition, but competition is assumed to be considered in the demand assumptions applied, resulting in market share based on the market analysis.

The current assumption is that the fixed cost to build/transition a station is the same for each station. At this point in the analysis, this is a fair assumption. Though there might be some variation in land costs and the tax base, these variations should be minor in a common metropolitan region. Further, such variations are minor compared to the size of the investments discussed.

The scope of this analysis was focused on the 42 zip codes in Fairfax County to provide a representative sample. This provides an initial basis for the investment analysis, and is solvable within the licensing constraints of academic software available at the university. If the recommendation is to invest, the formulation can be scaled to a national scope without much difficulty. We have already discussed the possibility for using the current formulation, while only requiring a variation in land use and other fixed costs. This only requires changing the data. Further, the algorithm used (network simplex) is a polynomial-time algorithm, able to scale up to a much larger number of nodes, while keeping computation time feasible.

4.4 Results

In the base case, using a 10k psi trailer under medium demand and pricing scenarios, we estimate the $75M capital investment to have a $13M NPV. In this scenario, four stations are initially required in 2015 in only four zip codes, expanding to a total of 13 by the end of the 10 year period for the metropolitan area under consideration. Figure 10 below shows the total stations required in these locations Overall, we estimate $126M in total revenue over this period from these stations, with a total operating cost of $38M.

Total Stations Required, by Year and Location											
	Year										
Zip Codes	1	2	3	4	5	6	7	8	9	10	Total
20170	1	1	1	1	1	2	2	2	3	4	**4**
22030	1	1	1	1	1	1	1	2	2	3	**3**
22151	1	1	1	1	1	1	1	1	2	2	**2**
22308	1	1	1	1	1	2	2	2	3	4	**4**
Total	**4**	**4**	**4**	**4**	**4**	**6**	**6**	**7**	**10**	**13**	

Figure 10. Total Stations Required, by Year and Location (base case)

As expected, the stations are geographically dispersed, and concentrated in high population areas with high household incomes. The locations correspond to Herndon, Fairfax City (GMU), North Springfield, and Mount Vernon.

4.4.1 Conclusions & Sensitivity Analysis

Figure 11 below shows the sensitivity of the results to variations in demand, retail price, or the operating cost (as driven by the trailer technology used). The chart shows that the locations selected are primarily driven by

the variations in demand. Fortunately, the site chosen in a low demand scenario are chosen in all scenarios, so these represent a good conservative starting point for the investment.

	Scen #1	Scen #2	Scen #3	Scen #4	Scen #5	Scen #6	Scen #7	Scen #8	Scen #9	Scen #10	Scen #11	Scen #12	
Price	lo	lo	lo	lo	lo	med	med	med	hi	hi	hi	hi	
Demand	lo	lo	lo	med	med	med	med	med	med	hi	hi	hi	
Op Cost	0.60	1.63	3.21	1.63	1.63	0.60	1.63	3.21	1.63	0.60	1.63	3.21	
Zip Code													**Total**
20120									3	11	11	11	**11**
20170	3	3	3	4	4	4	4	4	3	7	7	7	**7**
20194										4	4	4	**4**
22030				3	3	3	3	3	3	7	7	7	**7**
22039										6	6	6	**6**
22042										2	2	2	**2**
22044										7	7	7	**7**
22066									2	4	4	4	**4**
22124										4	4	4	**4**
22151						2	2	2					**0**
22152										4	4	4	**4**
22181									2				**0**
22307	3	3	3						3	10	10	10	**10**
22308				4	4	4	4	4					**0**
Total	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**3**	**11**	**11**	**11**	**11**

Figure 11. Sensitivity Analysis

Retail prices and the trailer technology have significant impacts on NPV, but negligible impacts on the timing and locations for the stations to transition. Results of the dual program analysis support this conclusion, and can be found in Appendix C: Station Location Analysis.

Future work should address the following shortfalls in the model that arose to the limited time of this effort:

- The current model does not make enough allowance for the fact that current demand is met in a location, and therefore should be discounted when looking at the next incremental investment.
- The current model is constrained primarily off of meeting demand and maximizing total profit. It does not consider enough of the marginal profit within the constraints; therefore the primary sensitivity factor is demand (rather than revenue or gross margin).

That said, the model provides a useful tool for updating the investment strategy periodically, as greater information is obtained about vehicle adoption rates, populations, and delivery technologies. We believe that future iterations of this program could be modeled as a min-cost network flow, greatly improving its scalability and performance.

5 Business Strategy / Business Approach

The Hydrogen Team is the product developer in an oil company.

5.1 Market Analysis

We estimate that the size and growth of the market for alternative energy vehicles will mirror the situation with gasoline-electric hybrid vehicles. The Toyota Prius gasoline-electric hybrid vehicle was launched in the U.S. in 2000, and is the landmark product that leads that market. Given its prevalence and easier availability of data, we used Prius sales a proxy for our adoption scenario. If the Prius sales rates continue to grow, by 2010, it will have over 2.5% share of the US auto market (refer to Figure 12 and Figure 13). See Figure 65 for Prius Sales Growth and Figure 66 for Prius Annual Sales in Appendix C.4: Expected H2 Adoption Scenarios.

Since the introduction of the Prius several other hybrid cars have been released and currently over 4% of new car sales are hybrid vehicles. Currently, about 40% of the hybrid vehicles on the road are Prius. The Hydrogen Team is assuming hydrogen cars will follow the same market adoption over a similar period of time.

The Prius and hybrid adoption curves were used because they most closely represents the characteristics of the hydrogen. Hybrids are environmentally friendly and achieve high fuel efficiency which are both goals for hydrogen vehicles. Alternatives that were considered but not used were electric cars, diesel cars, and bio-mass fuel cars.

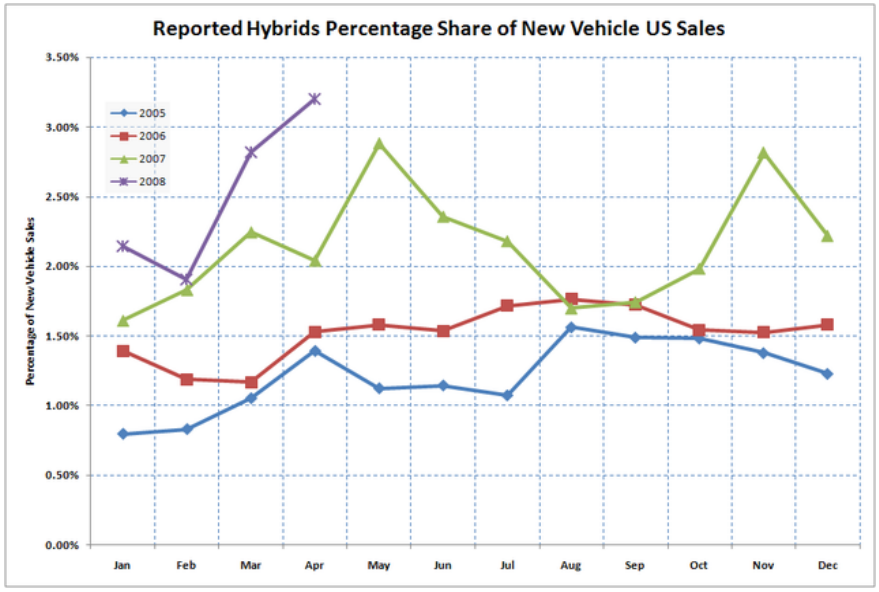

Figure 12. Hybrid Adoption (Market Share). (http://bioage.typepad.com/)

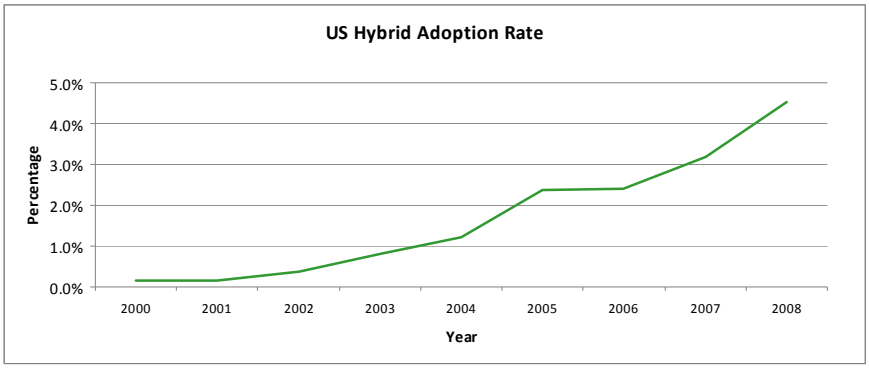

Figure 13. US Hybrid Adoption Rate.

To scale the analysis to the schedule and budget of this effort, the Hydrogen Team is specifically focusing on Fairfax County which is part of the Washington DC metropolitan area. According to a 2006 study by the National Renewable Energy Laboratory (NREL) the Washington DC metropolitan area has a high level of demand for a hydrogen infrastructure which supports a strong hydrogen vehicle adoption rate.

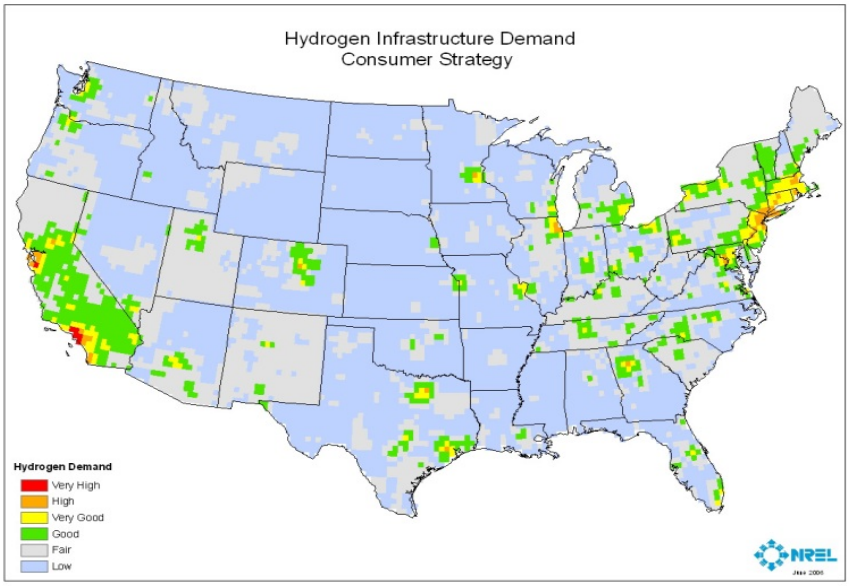

Figure 14. Hydrogen Infrastructure Demand (Continental U.S)

Based on the Prius gaining 1% market share within 6 years of being introduced it is assumed that a hydrogen car will follow the same technology adoption curve (refer to Figure 14 and Appendix A.9: Expected H2 Adoption Scenarios).

Relative Hydrogen Vehicle Demand Weightings	Individual Cell (20 × 20 mi^2) Hydrogen Fuel Demand (1,000 kg/day)		
	1% Penetration	5% Penetration	10% Penetration
Very high	302	1,508	3,016
High	251	1,257	2,514
Very good	201	1,005	2,011
Good	151	754	1,508
Fair	101	503	1,005
Low	50	251	503

Table 1. Annual Hydrogen Fuel Demand, Based on Relative Consumer Demand for Hydrogen Vehicles

It is assumed that a low market adoption rate will be 0.1%, medium adoption rate 1.0%, and high adoption rate of 5.0%. The probability of achieving each of these market adoption rates is 70%, 20%, and 10% respectively. It can be assumed that demand is equivalent to the market's adoption rate (refer to Table 1).

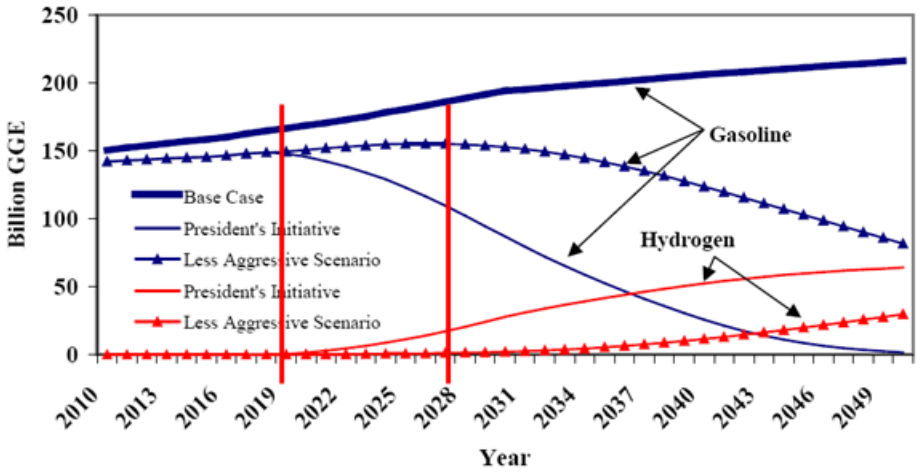

Figure 15. Hydrogen and Gasoline use for Light-Duty Vehicles

Figure 15 contains market projections published by the Department of Energy utilizing the Vision model. There are three different projections for Hydrogen and Gasoline usage: 1. A base case, where Hydrogen is not used as a fuel for end users, 2. A projection based on the adoption of the President's Initiative which is very aggressive and 3. A slightly less but more reasonable projection.[5] Based on the above, it is projected given either scenario that gasoline sales will begin to decline between 2020 and 2028, at a time when adoption rates for H_2 FCV's will be fairly low but rapidly increasing, between 3 -4 %. The only way to counter this would be to supply more gasoline and/or to provide a Hydrogen Delivery System capable of delivering H_2 to the end user. Since oil, the key feedstock for gasoline, diesel, will not meet current demands in the foreseeable future, the only alternative is to provide an adequate supply of H_2 in order to compensate for the loss of revenue from declining gasoline sales.

[5] More information about these projections can be found at "Report to Congress Effects of a Transition to a Hydrogen Economy on Employment in the United States", DOE Report to Congress, July 2008, http://www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf, page 67

5.2 Market Introduction Approach

As an oil company, one alterative option to enter the Hydrogen distribution market is to partner with a company like a Praxair, Air Products, Air Liquide to produce and distribute the fuel to fuel stations.

This offers several advantages for the oil company:

- Shared risk between companies reduces the amount of risk that the oil company takes on, in order to enter the market. If Hydrogen fuel cell vehicles do not take off, then the oil company is not as exposed (minimal capital investment was made).
- Turns a fixed capital cost into more of a variable pay-for-use cost. This reduces many of the upfront costs required for market entry. As the oil company learns more about the business and the market justifies it, they can start to invest into building out production facilities and distribution or they can decide to buy the hydrogen energy provider company.

Later in the Initial Phase, we will explore producing the hydrogen ourselves, acquiring our partner(s) or continuing with the current supply chain. Partnering with another company has advantages like spreading the risk and reducing fixed capital costs. However, if we as the oil company are serious about entering the hydrogen distribution market then we should control the entire supply change and leverage our experience in distributing fuel and selling fuel at stations. The strategy was developed after considering several alternatives in Figure 8 and illustrated in Figure 7Figure 42.

5.3 Go-to-Market Strategy

As the market develops, particularly in metropolitan areas, the oil company would co-locate production with current terminals. This in essence would flatten the distribution network by converging the Hydrogen production facility and the terminal and may be accomplished by steam reforming Hydrogen from natural gas at the new production facility and delivering it by truck to the fuel station from there. Due to the plentiful supply of Natural Gas and the elaborate transmission network, the production/terminal would have easy access to Natural Gas in order to produce Hydrogen.

Refer to Figure 166. During the early stages of the Initial Phase, The Hydrogen Team will participate, contribute, fund commercialization efforts of key system technologies and important external technologies (Fuel Cell Stacks, Vehicle Storage, Production Technologies). We will also participate in codes and standards bodies to develop a complete set of codes and standards which apply to the system (interfaces, functionality, system characteristics & performance) and promote standards adoption to ensure a large supplier ecosystem. This will require active engagement on our part in standards development and support (financial and in kind) for development of standards and technologies that are critical to our roadmap. This will drive upfront investment costs lower by creating a competitive supplier base and will lower maintenance and upgrade costs during the operation of the system. High levels of modularity will be obtained by adopting a standards-based component approach from the top-tier system supplier down to the lowest tier component supplier. Supplier tiers pushing standards-based procurement approaches to their suppliers will be in their best interests as long the supply belongs to a large highly competitive tier.

The Hydrogen Team will influence regulations and policy at key federal, state and local government agencies by working with key decision makers in updating, creating laws, regulations, codes and right-of-way / eminent domain decisions. Specifically, we will focus the majority of our influencing activities on the Department of Transportation (DOT) in order to ease regulations related to tank trailer and pipeline pressures, currently at 2640 psi and 125 psi and increase them to 10 k psi and 2200 psi respectively (objective). Our objective is to create an environment friendly to a hydrogen economy by avoiding and removing barriers to system build-out, market-entry, and operation.

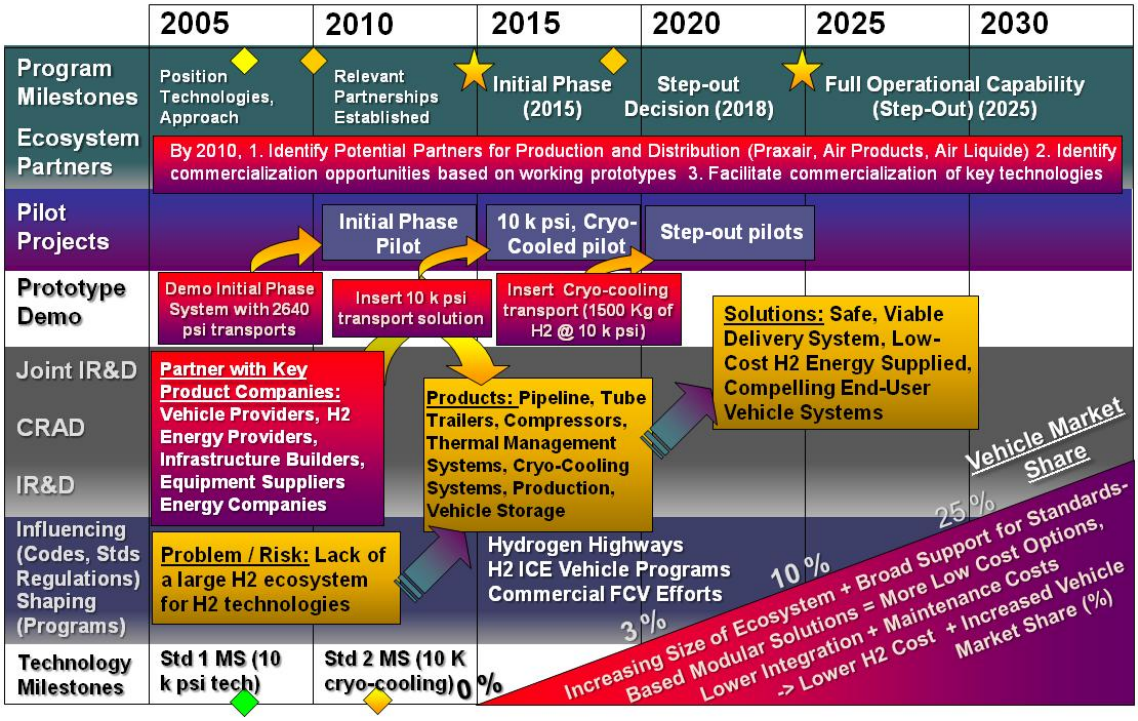

Figure 16. System Technology and Business Roadmap

5.4 Supporting System-Life Cycle

Two use cases will be supported with this architecture:

- During the initial phase, the hydrogen distribution system will follow a centralized production and terminal distribution model, leveraging capabilities of current hydrogen energy partners.
- During the "Step-Out" phase, the distribution system is flattened with production being moved to terminals following a centralized hybrid distribution model. This will lower delivery costs significantly, which is a major component to the retail cost of H_2.

The initial phase will follow a standard waterfall development life-cycle, with this version of the system being supported until a commercialization decision on the "Step-Out" is made

The "Step-Out" phase will follow a spiral development life-cycle:

- Initial spirals will assess transport technologies in order to minimize risk as the market develops (Compressed H_2 / Cryo-cooling @ 10 K)
- System build-out will start during early stages of sharp increases in market penetration of Light-Duty H_2 FCV's, which is currently projected to occur during 2018, 2019
- System build-out will be completed by 2025, as market adoption of H_2 FCV's accelerates (sometime between 2022 and 2025)

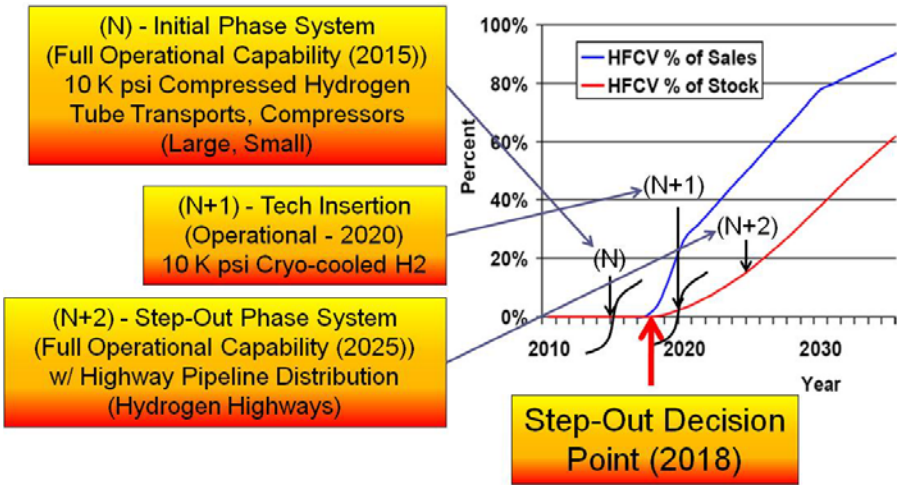

Figure 17. Technology Insertion Points[6]

Since the development life-cycle depends highly on market timing, the market will need to be constantly monitored in order to establish early production ramp up of FCV's, market adoption rate and adoption levels. Figure 177 illustrates technology insertion points in respect to Hydrogen FCV market adoption rates and adoption levels. There are roughly three stages of the delivery system planned with the key decision point for the Step-Out strategy occurring 2018, with key technology insertion points in 2015 (Compressed H_2 @ 10 k psi) and 2020 (Cryo-cooling solution to get to 1500 Kg of H_2 delivered). S-curves were transposed on the market curves to indicate maturing of these two emergent technologies with respect to time. Stage (N) represents the Initial Phase (Full Operational Capability) and the introduction of 10 k psi tube trailer and compression technologies for hydrogen. Stage (N+1) represents the introduction of cryo-cooling techniques. This potentially could be introduced earlier in the development cycle if needed. Stage (N+2) represents the Step-Out Phase (Full Operational Capability) and the addition of pipeline distribution, particularly along highways or other low-cost right-of-ways.

5.5 Cost Analysis, NPV, and Influence Diagram

5.5.1 Base Case Cost Analysis and NPV

The DOT has a limit of 2640 psi on all large compressed vehicle payloads. Currently 2640 psi hydrogen tankers can hold 280 Kg of hydrogen. A hydrogen station with heavy demand will require approximately 1500 Kg of hydrogen per day so over 5 deliveries will be needed to be made each day. The current hydrogen tanker technology results in a negative net present value of $54,467,791 over a 20 year period of time as can be seen in the graph (in Figure 18. Baseline Cash Flow8) and chart (in Table 2) below. The long term corporate bond rate for AAA companies is 6% and was used for our NPV calculations. ExxonMobil is one company that falls in the AAA company category.

Cost Analysis Summary			
NPV	Kg / Tanker	Demand	Price
$ (54,467,791)	280	Medium	Medium

Table 2. Base Model Cost Analysis

[6] "Report to Congress Effects of a Transition to a Hydrogen Economy on Employment in the United States", DOE Report to Congress, July 2008, http://www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf

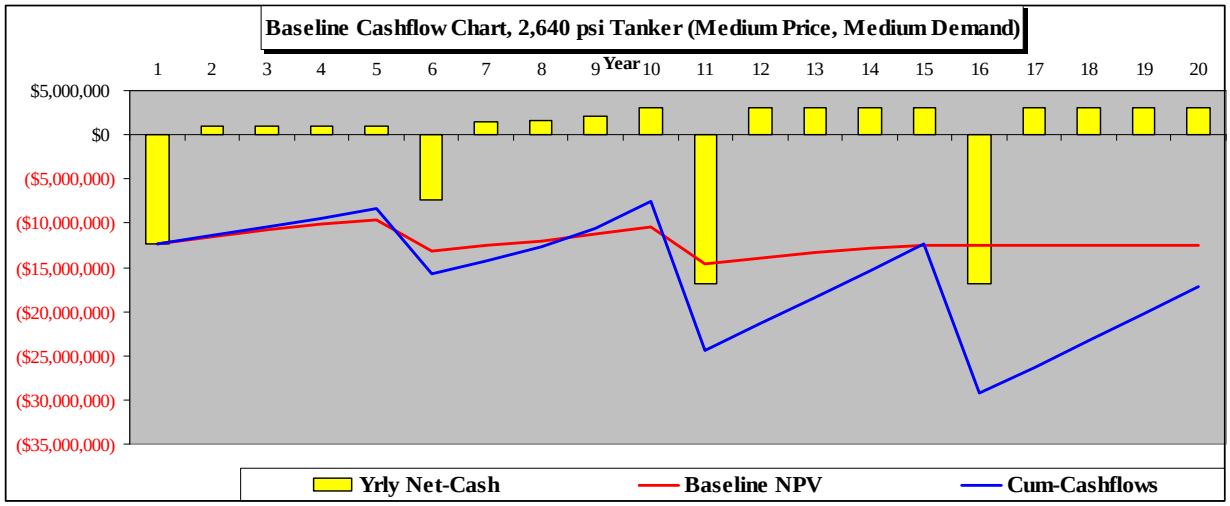

Figure 18. Baseline Cash Flow

5.5.2 Life Cycle Cost Estimate

The Hydrogen Station Cost Analysis and Tanker Cost Analysis are provided in the appendices. Based on DOE Hydrogen Model, we are assuming that the stations are recapitalized every 20 years and the tankers are recapitalized every 5 years.

5.5.3 Alterative Scenarios, Cost Analysis and NPV

Alternative pricing and high capacity tankers are options being considered to gain a positive NPV.

DOE's goal was deliver hydrogen at less than a dollar per Kg so the sales price of hydrogen can range from one dollar per Kg up to a price that is comparable to gasoline. The Hydrogen Team will use a range up to eight dollars per Kg for cost estimating and the influence diagram. Additionally, if the price of gasoline stays at a level that is less than what hydrogen can be delivered then there would be no advantage to the consumer to switch from gasoline to hydrogen.

Currently, high capacity hydrogen tankers are being developed which will hold 550 Kg of hydrogen under 5000 psi and 1500 Kg of hydrogen using a cryo-cooling technology. Higher capacity tankers will dramatically reduce the cost per Kg to deliver hydrogen. Table 3 shows a cost summary to implement a hydrogen station along with the operations and maintenance costs associated with delivering hydrogen.

O&M Costs for Current and Future High Capacity H2 Tankers							
	1 Station	1 Tanker	Station Cost/ Kg	Tanker Cost/ Kg @280Kg/tanker (2,640 psi)	Tanker Cost/ Kg @550Kg/tanker (5,000 psi)	Tanker Cost/ Kg @1100Kg/tanker (10,000 psi)	Tanker Cost/ Kg @1500Kg/tanker (Cryo-cooled)
Fixed Capital Cost (20 yr. RECAP)							
Major Pieces/Systems of Equipment	$ 1,768,721		$ 0.16				
Station Costs	$ 489,680		$ 0.04				
Fixed Capital Cost (5 yr. RECAP)							
Tanker Cost		$ 415,185		$ 1.08	$ 0.55	$ 0.28	$ 0.20
Fixed O&M							
Station O&M	$ 1,090,599		$ 1.99				
Variable Costs							
Tanker O&M		$ 246,036		$ 3.21	$ 1.63	$ 0.82	$ 0.60
Subtotal	$ 3,349,000	$ 661,221					
Total	**$ 4,010,221**						

Table 3. Hydrogen Station and Tanker Fixed and Variable Costs

We performed a cost and NPV analysis for tankers with capacities of 280 Kg, 550 Kg, and 1500 Kg with varying demands. The long term corporate bond rate of 6% for AAA companies was used to calculate the NPV. Table 4

is a summary of the NPVs for each of the three tanker capacities with varying demand and price. Appendix C: Station Location Analysis contains NPV and cumulative cash flow graphs for each of the scenarios.

Cost Analysis Summary				
NPV	Break Even Point	Kg / Tanker	Demand	Price
$ (35,172,921)	-	280	Low	Low
$ (54,467,791)	-	280	Medium	Medium
$ (115,748,744)	-	280	High	High
$ 53,319,147	Year 3	550	Low	Low
$ 72,194,467	Year 3	550	Medium	Medium
$ 167,684,392	Year 2	550	High	High
$ 107,281,753	Year 2	1500	Low	Low
$ 159,106,580	Year 2	1500	Medium	Medium
$ 353,103,052	Year 2	1500	High	High

Table 4. NPV Summary for Varying Tanker Capacities

5.5.4 Influence Diagram

As described in Section 4, our team developed a linear program to determine the number of stations required to meet demand in each of the zip codes in Fairfax County based on adoption rates over time. We used the output number of stations in each year of adoption to perform the cost analysis as well as develop an influence diagram (in Figure 1919). The major decision in the influence diagram below is the number of stations. In addition, there are three discrete chance nodes that represent the Market Adoption Rate, Sales Price, and Type of Taker used. The Market Adoption rate uses the adoption rates and probabilities from the table in the Market Analysis section. The Sales Price varies between one dollar and eight dollars per Kg. This influence diagram does not consider that if the price of hydrogen rises then the market adoption will decrease and vice versa. The tanker type is dependent on government regulation and technological advances in hydrogen tankers. Currently, only the 2640 psi tanker is available but progress is being made with the 5000 psi and cryo-cooled tankers. There is a 90% probability that the 2640 psi tanker will be used which can deliver 280 Kg of hydrogen. There is a 7.5% probability that the 5000 psi tanker will be selected and it can deliver 550 Kg of hydrogen. The cryo-cooled tanker has a 2.5% probability of being used and can deliver the most hydrogen at 1500 Kg per tanker.

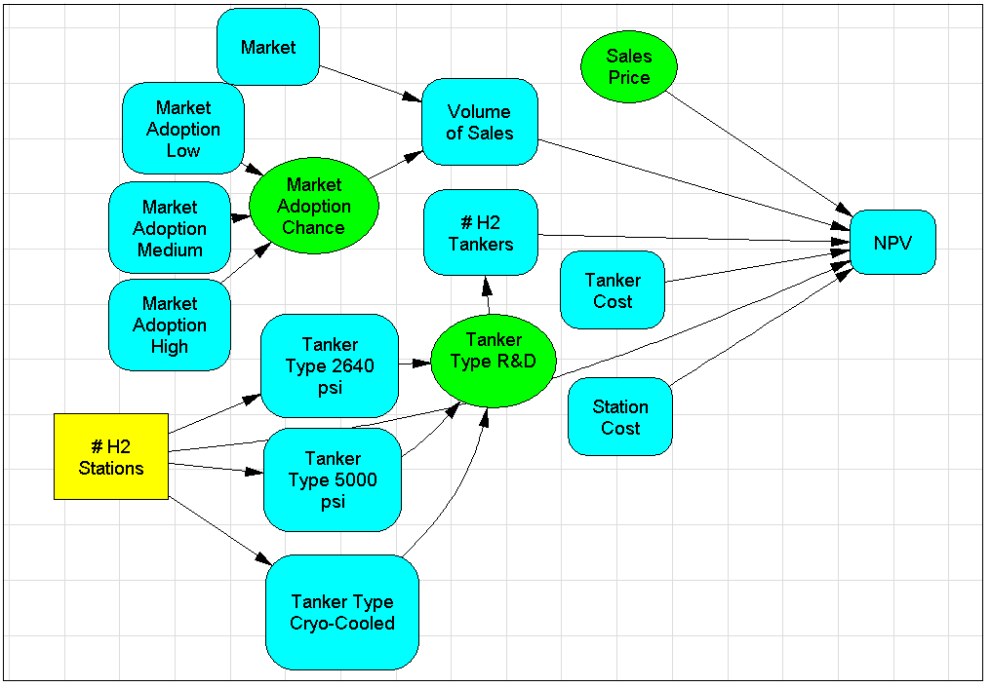

Figure 19. Influence Diagram

The tree diagram in Figure 42 shows the possibilities for the decision node and the three discrete chance nodes.

Using DPL, a decision analysis is run and one of the outputs is a Policy Summary, shown below, which represents the outcome when the NPV is maximized. The maximum number of stations were selected which is the same result as the linear program model which had the highest NPV when more stations were used.

Market Adoption, Tanker Type, and Sales price are all chance nodes because as an oil company distributing hydrogen we have limited control over how many people purchase hydrogen cars, government regulations on tanker pressures, and the relative price of hydrogen compared to oil. To maximize market adoption rates it is important to work with auto manufactures to ensure the availability of hydrogen vehicles coincides with the availability of hydrogen fuel stations. The use of higher capacity hydrogen tankers depends both on technological developments and government regulation both of which the oil company will make considerable investments to aid in their success. The three discrete chance nodes were assigned probabilities based on market adoption, tanker development, and sales price research and they each follow their assigned probabilities (refer to Figure 19).

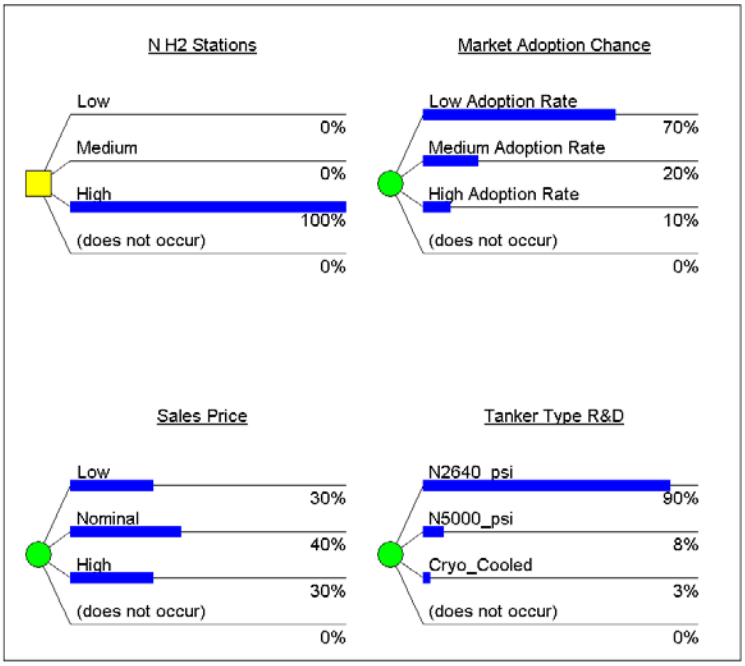

Figure 19. Policy Summary

5.5.5 Value Tornado

A Value Tornado diagram is another output from DPL which is a sensitivity analysis of the inputs into the influence diagram. The tornado diagram in Figure 20 shows that the most sensitive input to the NPV is the cost of the hydrogen tankers which is directly related to type and number of tankers in the objective function. Depending on the type of tanker; 2640 psi, 5000 psi, and cryo-cooled, the cost per Kg to transport hydrogen varies greatly, between $3.21 and $0.60. For the business strategy, it is critical that regulations be changed to support higher pressure hydrogen tankers. Otherwise, we do not have a supporting business case or a profitable business. An alternative would be that we produce hydrogen at the stations; however the upfront costs to this approach would be substantial in equipment, energy and ongoing maintenance costs.

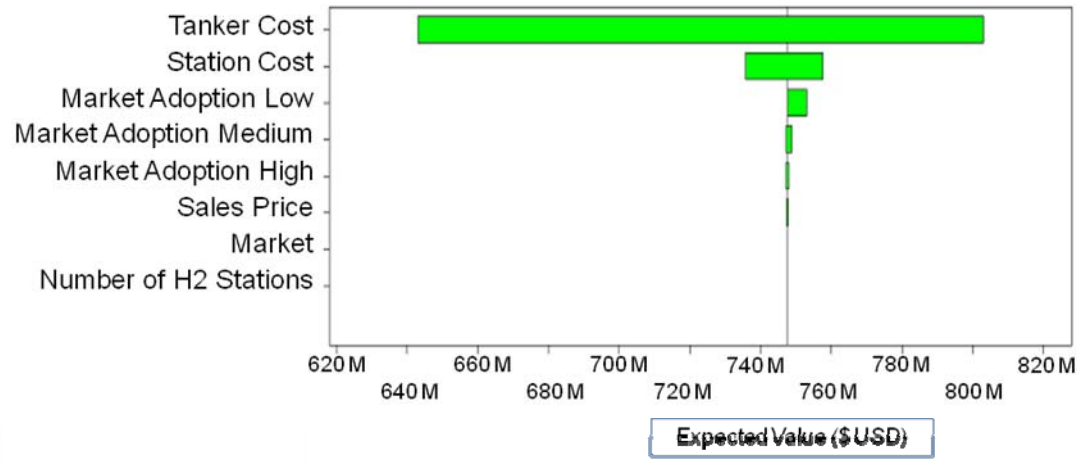

Figure 20. Value Tornado Diagram

5.5.6 Cumulative NPV Probability Distribution

The cumulative NPV probability distribution (see Figure 21Figure 21) below is based on the variances of the variables that influence the NPV and probability at which there is a positive NPV. There is less than a 2.5% probability of a negative NPV when including possibilities such as low and high market adoption rates, low and high prices, and three different types of hydrogen tankers.

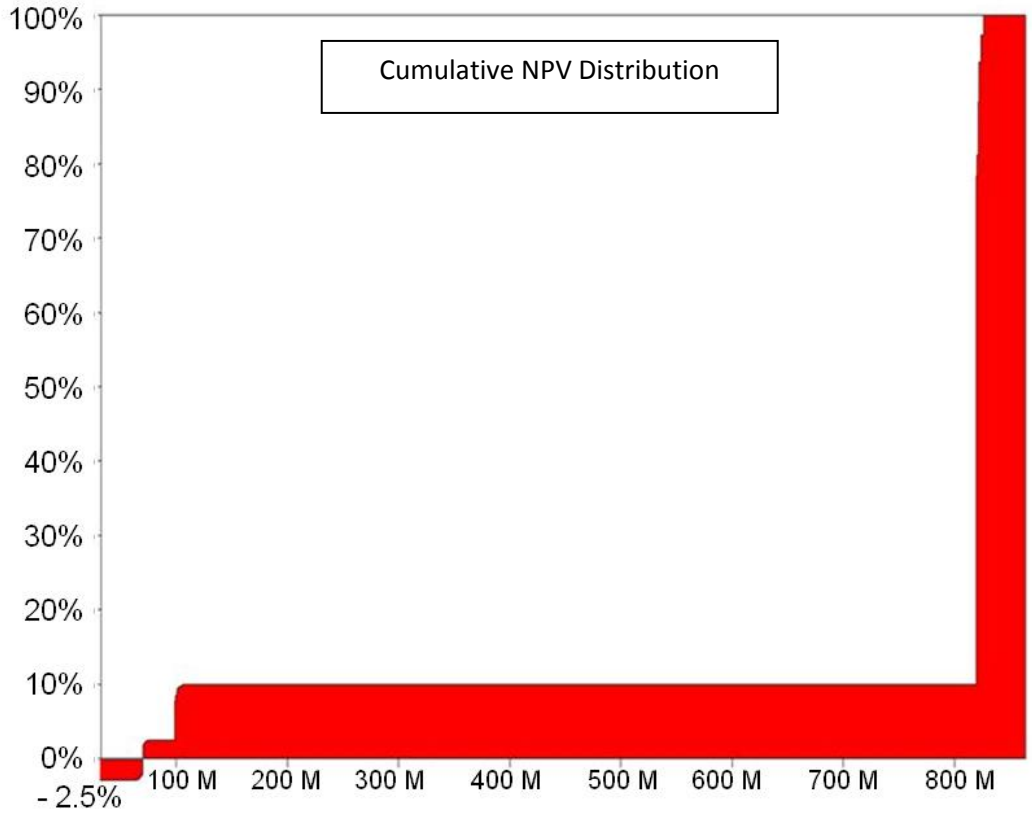

Figure 21. Cumulative NPV Distribution

5.6 Risk Analysis

The major risks of this project are categorized by Cost, Technical and Schedule (more information regarding program risks can be found in Appendix A.7: Program Risks). Each risk has a risk mitigation strategy, status, probability and an Overall Risk Importance which is calculated as the sum of Schedule, Cost and Performance Impact. Impact Scores are on a scale of '0' (No Impact) to '10' (Extremely High Impact). Of the eleven risks listed below, R001, R002 and R011 (refer to Figure 22) are highly probable and critically impact the system and must be aggressively pursued. Risk R001 relates to the 2640 psi regulatory limit on compressed hydrogen vehicle transport which negatively impacts NPV. The mitigation strategy is to influence the Department of Transportation (DOT) to increase vehicle transport pressures for hydrogen to 5 k psi or 10 k psi and to introduce new technologies such as cryo-cooling to increasing energy densities at 2640 psi. Risk R002 relates to the 150 psi regulatory limit on pipeline transport of compressed hydrogen, severely limiting transmission and distribution lines. The mitigation strategy is to distribute hydrogen by vehicle transport, particularly within urban areas and influence the DOT to increase pipeline pressures, particularly in cases where pipeline transmission or distribution is more feasible and cost effective. Risk R011 relates to volatility in gasoline, diesel and ethanol prices impact price hydrogen can be sold, affecting NPV and investment decisions at any given time.

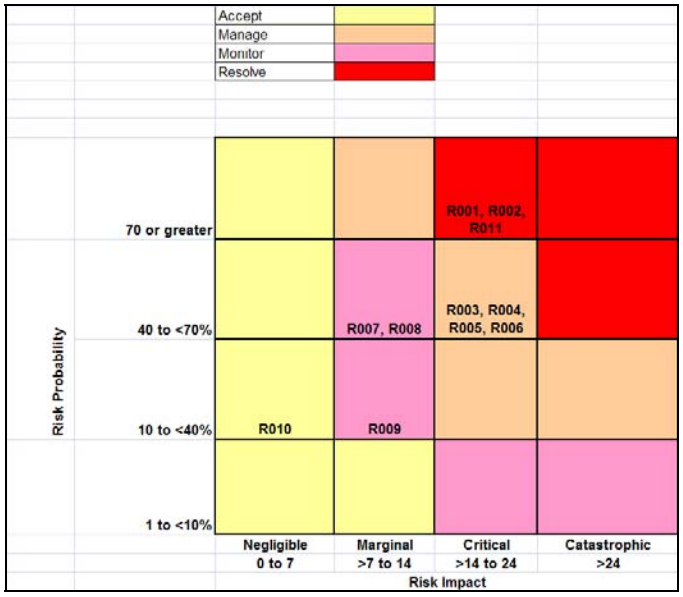

Figure 22. Risk Matrix

5.7 Business Strategy Conclusions, Recommendations

The 10 K psi option offers the best capacities for Compressed H_2 and is the only solution that comes close to meeting the average expected daily usage at a retail site by DOE (1500 Kg). However, the DOT has a limit of 2640 psi on all large compressed vehicle payloads. As a result, we will begin early adoption with 2640 psi tube trailers and continue to develop 5K and 10 K psi tube trailers with the expectation that the 5K or both may be approved for use by DOT. Though the 2640 psi tanker that is available for use does not provide a cost effective volume, higher capacity tankers such as the 5000 psi and cryo-cooled tanker will be available in the near future and will result in a positive NPV. Once 5K psi tankers with capacities of 550 Kg are available then the NPV is always positive. The most profitable, efficient approach in this environment is to deploy 10 k psi tankers with capacities of over 1500 Kg (NPV of $353 M) and technologies such as cryo-cooling though there are lower pressure / capacity scenarios where we will still be profitable (e.g. 5 k psi with NPV of $53 M or similar tank capacities at lower tank pressures with cryo-cooling).

This investment would represent a positive net present value 97.5% of the time. Alternatively, the probability of a negative NPV is less than or equal to 2.5%. The largest influence on the likely return is the likely retail price for H_2, which we set based on projections for retail gasoline prices. Our ability to shape or control this factor through regulation, partnerships, or our oil business unit will have the largest impact the likely success of this investment.

We recommend a $67 M investment over five years in the initial phase delivery system and to initiate partnering discussions with all three of the major Hydrogen Energy Providers in the U.S. We also recommend the expansion of the Initial Phase business case to a nationwide deployment and the development of the business case for the Step-Out phase.

As mentioned earlier in the report, declines in retail gasoline sales in the U.S. will occur, sometime between 2020 – 2028, as H_2 adoption rates start to rapidly increase. Sales in H_2 will be required to compensate for loss of revenue from declining sales of current fuel product offerings. We must invest in a Hydrogen Delivery System now in order to provide H_2 to fuel cell vehicle customers and meet this emerging challenge to the oil business.

6 References

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Note: The following represents all of the references which contributed to Assignments #1, #2, #3 and #5.

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Appendix A: Additional Paper Reference Material

Appendix A.1: Quality Function Deployment (QFD)

After prioritizing needs, Team Hydrogen mapped the needs to system characteristics. These characteristics represent the forward definition of specifications based on values from stakeholder "wants and needs" and were defined to address the underlying issue(s) defined during value mapping process. Next Team Hydrogen identified relationships between stakeholder needs and characteristics and evaluated specifications based on the relationships with stakeholder wants and needs. The result is the completed QFD in Figure 23. The QFD contains a prioritized set of system characteristics mapped to stakeholder needs.

The analysis identified needs and their relationships to system characteristics. For example:

- Need: Low capital equipment cost, Specification: create a modular system and use parts of existing infrastructure
- Need: Hydrogen as a low cost fuel alternative, Specification: System relies on domestic production

Correlations were identified between Specifications. Negative correlations revealed specifications that may conflict, for example: Low cost and complies with regulations. Positive correlations were identified which were related and may overlap.

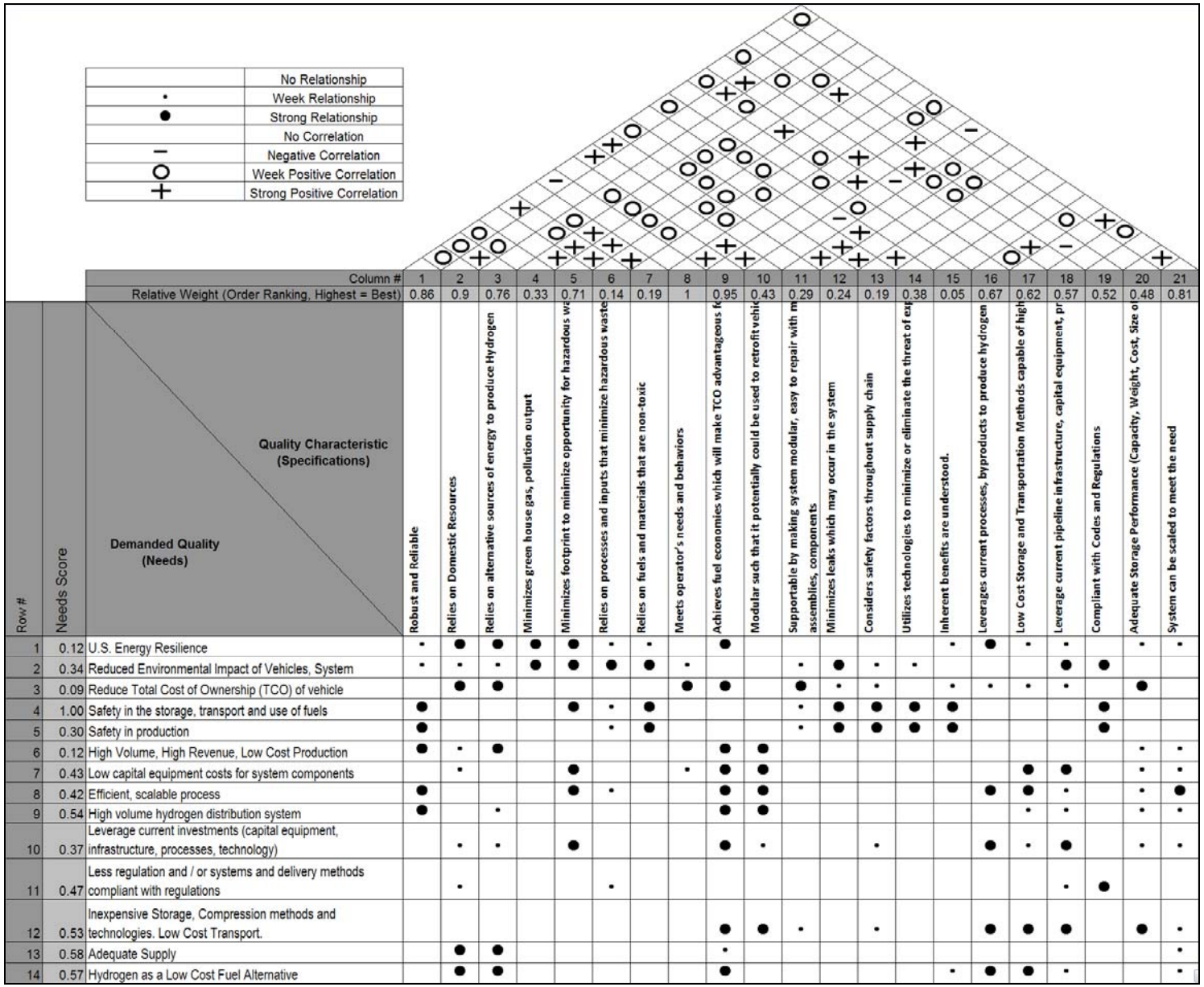

Figure 23. Quality Function Deployment (QFD)

Appendix A.2: Functional and Physical Decomposition

Initial Functional and Physical Decompositions were derived from the Quality Characteristics and Stakeholder Needs in the QFD and the Operational Concept / Context and input into and maintained with Core v5.0, an architecture development tool developed and provided by Vitech Corporation. The following figures represent the latest functional and physical component decompositions.

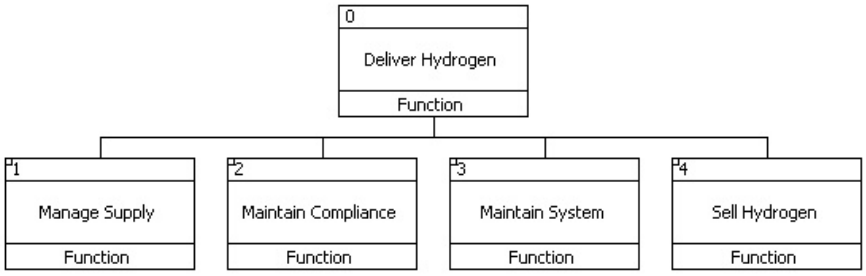

Figure 24. Functional Decomposition (Deliver Hydrogen)

Deliver Hydrogen is the A-0 level function and is responsible for performing the mission to Delivery Hydrogen Energy.

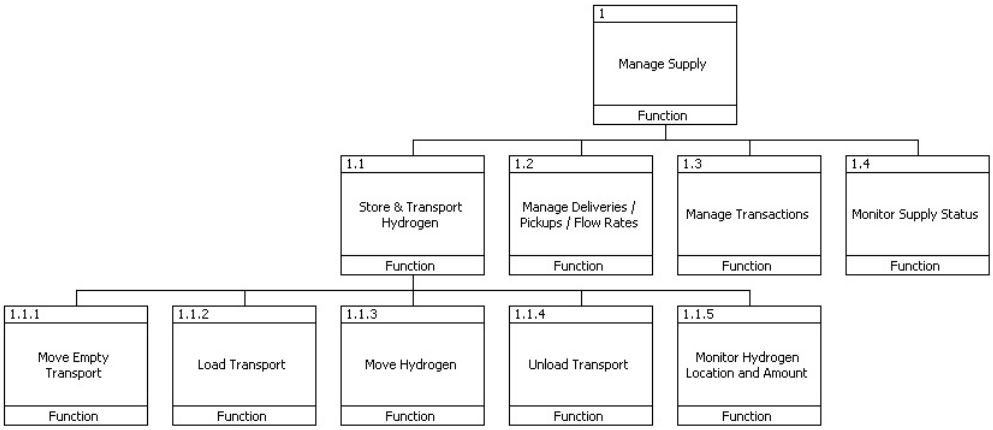

Figure 25. Functional Decomposition (Manage Supply)

Manage Supply function is responsible for the Managing the flow of the Hydrogen through the Hydrogen Delivery System

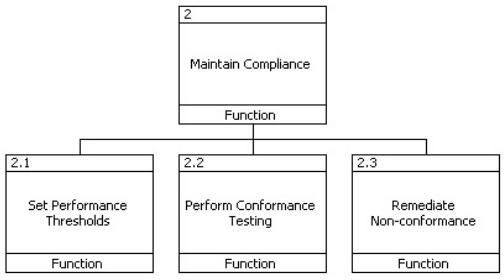

Figure 26. Functional Decomposition (Maintain Compliance)

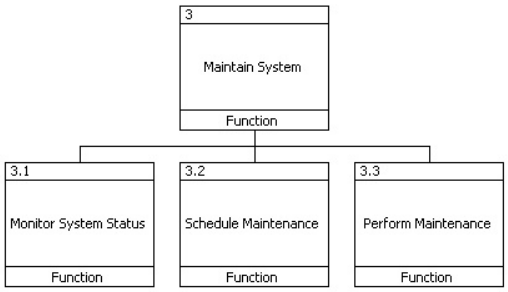

Figure 27. Functional Decomposition (Maintain System)

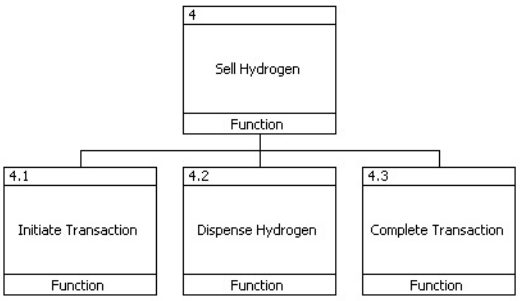

Figure 28. Functional Decomposition (Sell Hydrogen)

Table 5 contains further description of the functions contained in the decomposition.

Table 5. Function Descriptions

Number & Name	Description
0 Deliver Hydrogen	Performs the Delivery Hydrogen Energy mission.
1 Manage Supply	Manage Supply function is responsible for the flow of hydrogen through the Hydrogen Delivery System.
1.1 Store & Transport Hydrogen	The Store & Transport Hydrogen function is responsible for the transport and f hydrogen across the Hydrogen Delivery System.
1.1.1 Move Empty Transport	The Move Empty Transport function is responsible for positioning empty transports at producer or terminal locations in order to accept a load of hydrogen energy.
1.1.2 Load Transport	The Load Transport function is responsible for, 1. Initiating the Load Transaction 2. Loading the transport with hydrogen 3. Completing the load transaction
1.1.3 Move Hydrogen	The Move Hydrogen function is responsible for transporting the delivery vehicle to terminal or fuel station destinations.
1.1.4 Unload Transport	The Unload Transport function is responsible for, 1. Initiating the Unload Transaction 2. Unloading transport storage 3. Completing the unload transaction
1.1.5 Monitor Hydrogen Location and Amount	Monitors hydrogen supply via reports from vehicle transports.
1.2 Manage Deliveries / Pickups / Flow Rates	Schedules and manages hydrogen deliveries and delivery requests

1.3 Manage Transactions	Manages all delivery transactions. Monitors and reports all completed delivery and sales transactions.
1.4 Monitor Supply Status	Monitors and reports the supply of hydrogen in the system.
2 Maintain Compliance	The Maintain Compliance function is responsible for setting performance thresholds for operational components, testing and measuring the system components against those thresholds and performing tasks to remediate any non-compliance, non-conforming equipment or hydrogen product.
2.1 Set Performance Thresholds	Sets the performance thresholds based on operational goals.
2.2 Perform Conformance Testing	Performs all testing for compliance, conformance.
2.3 Remediate Non-conformance	Remediates all non-conforming systems.
3 Maintain System	The Maintain System function is responsible for monitoring, maintaining and repairing operational systems and components.
3.1 Monitor System Status	Monitors status and requests maintenance.
3.2 Schedule Maintenance	Schedules maintenance and repair activities based on priority. Make recommendations on the maintenance actions and required skills, equipment and parts required.
3.3 Perform Maintenance	Performs the maintenance. Requests additional parts and equipment if required. Recommends an addition maintenance or repair that must be made to the system.
4 Sell Hydrogen	The Sell Hydrogen function is responsible for the retail sale of hydrogen.
4.1 Initiate Transaction	Initiates the dispenser based on customer input: selected payment method, pressure.
4.2 Dispense Hydrogen	Dispenses hydrogen when authorized. Meters the dispensed hydrogen.
4.3 Complete Transaction	Completes the sales transaction based on the hydrogen retail price and the amount of hydrogen dispensed.

The following is the Physical Decomposition for the Hydrogen Delivery System. A table describing the system components follows the figures.

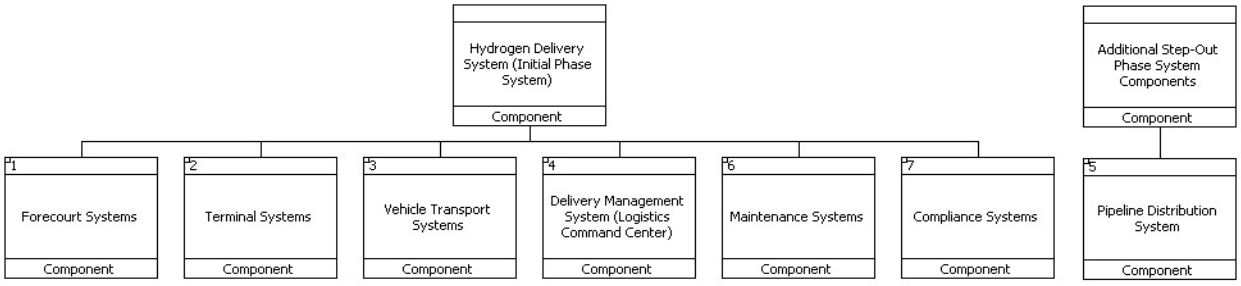

Figure 29. Physical Architecture Decomposition Diagram (Hydrogen Delivery System)

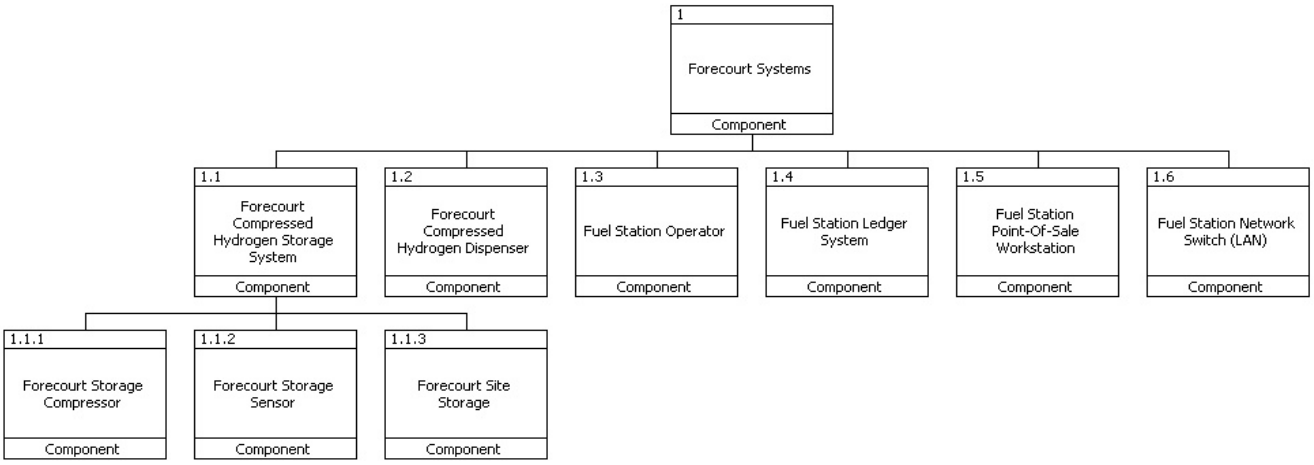

Figure 30. Physical Architecture Decomposition Diagram (Forecourt Systems)

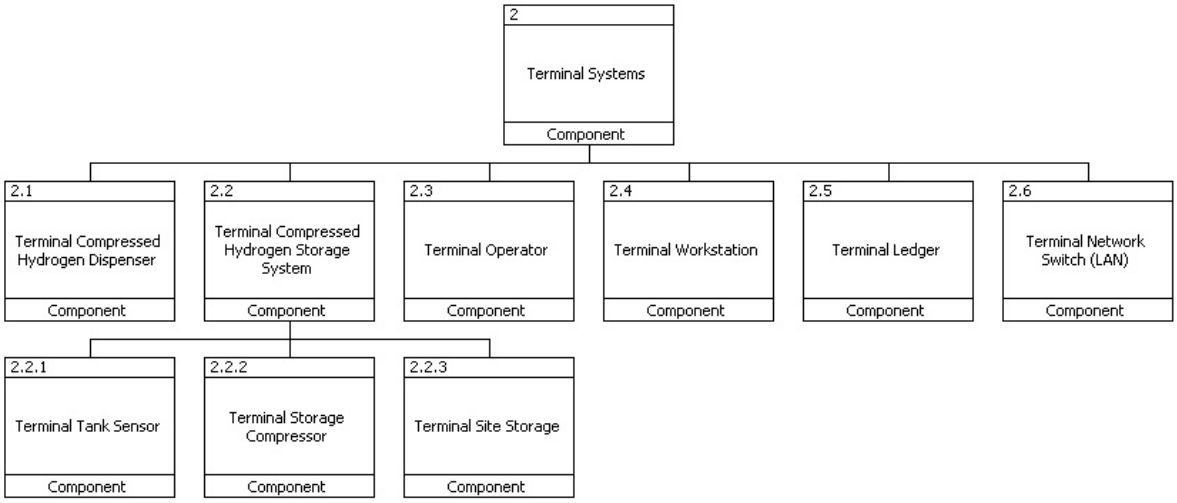

Figure 31. Physical Architecture Decomposition Diagram (Terminal Systems)

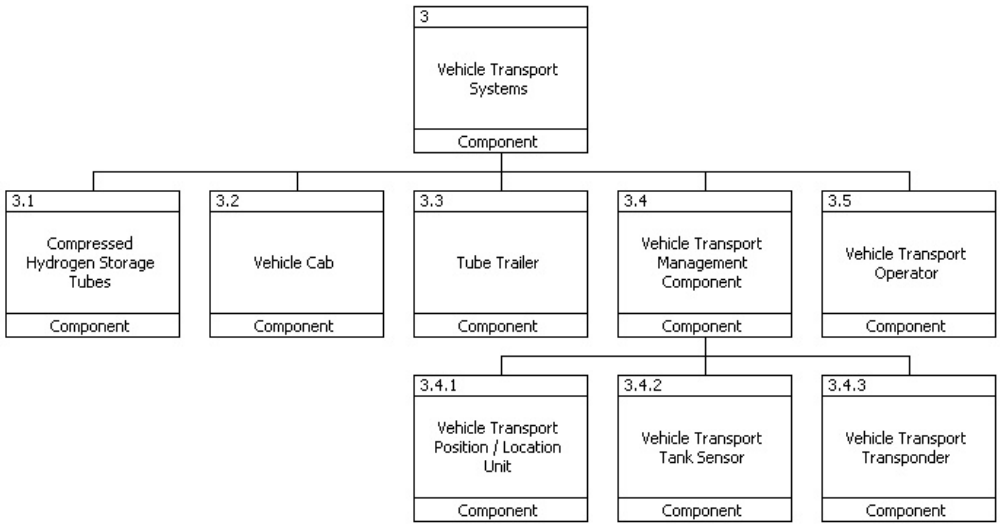

Figure 32. Physical Architecture Decomposition Diagram (Vehicle Transport Systems)

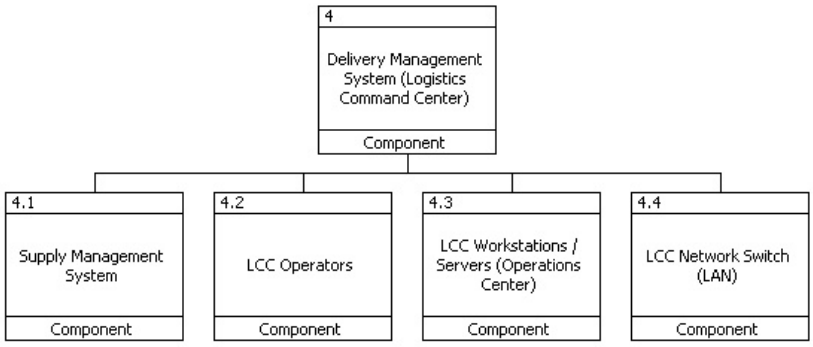

Figure 33. Physical Architecture Decomposition Diagram (Delivery Management System)

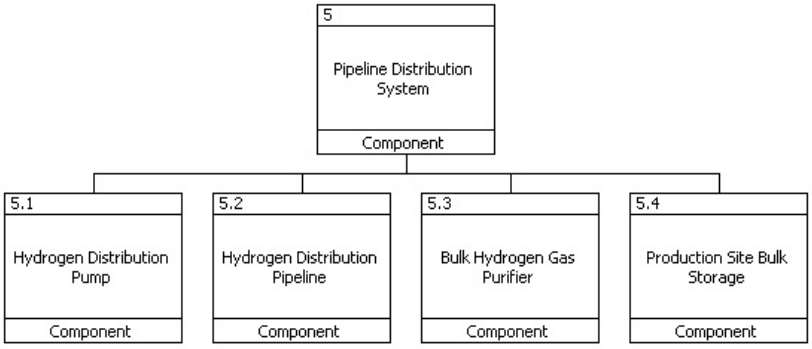

Figure 34. Physical Architecture Decomposition Diagram (Pipeline Distribution System)

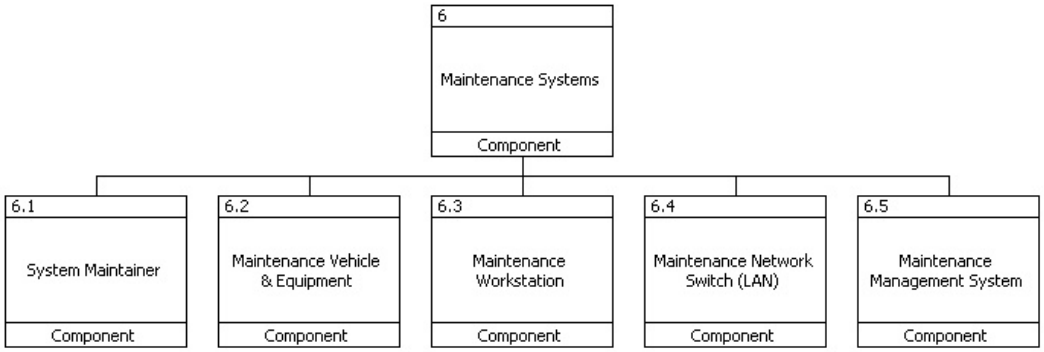

Figure 35. Physical Architecture Decomposition Diagram (Maintenance Systems)

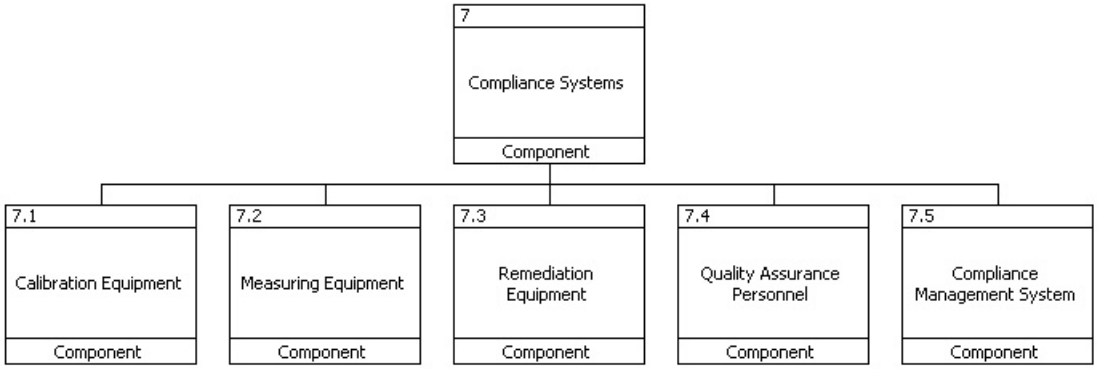

Figure 36. Physical Architecture Decomposition Diagram (Compliance Systems)

Table 6. Description of Hydrogen Delivery System Components

Number & Name	Description
1 Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
1.1 Forecourt Compressed Hydrogen Storage System	The Forecourt Compressed Hydrogen Storage System is responsible for receiving, storing and monitoring the hydrogen supply at the fuel station.
1.1.1 Forecourt Storage Compressor	The Forecourt Storage Compressor provides an interface to the Vehicle Transport to unload hydrogen deliveries to the fuel station forecourt.
1.1.2 Forecourt Storage Sensor	The forecourt tank sensor measures and reports on-site tank levels using pressure measurements and the known capacity of the fuel station storage tanks.
1.1.3 Forecourt Site Storage	Forecourt Site Storage receives hydrogen from vehicle transport and provides hydrogen to the fuel dispenser.
1.2 Forecourt Compressed Hydrogen Dispenser	The Forecourt Compressed Hydrogen Dispenser is the point-of-sale for customers.
1.3 Fuel Station Operator	The Fuel Station Operator is responsible for managing fuel station operations.
1.4 Fuel Station Ledger System	The Fuel Station Ledger System maintains an electronic record of transactions local to the fuel station.
1.5 Fuel Station Point-Of-Sale Workstation	The Fuel Station Point-Of-Sale Workstation is used to manage transactions and monitor operations at the fuel station.
1.6 Fuel Station Network Switch (LAN)	The Fuel Station Network Switch provides a shared network to support the local fuel station.
2 Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
2.1 Terminal Compressed Hydrogen Dispenser	The Terminal Compressed Hydrogen Dispenser provides an interface to load empty Vehicle Transports with hydrogen.
2.2 Terminal Compressed Hydrogen Storage System	The Terminal Compressed Hydrogen Storage System is responsible for receiving, storing and monitoring the hydrogen supply at the terminal facility.
2.2.1 Terminal Tank Sensor	The Terminal Tank Sensor measures and reports on-site tank levels using pressure measurements and the known capacity of the terminal on-site tanks.
2.2.2 Terminal Storage Compressor	The terminal compressor is employed while unloading hydrogen from a vehicle transport and directs it to terminal on-site storage.
2.2.3 Terminal Site Storage	Terminal Site Storage receives hydrogen from vehicle transport and provides hydrogen to the Terminal Compressed Hydrogen Dispenser.
2.3 Terminal Operator	The Fuel Station Operator is responsible for managing fuel station operations.
2.4 Terminal Workstation	The Terminal Workstation is used by Terminal Operators to manage transactions and monitor operations at the terminal facility.
2.5 Terminal Ledger	The Terminal Ledger System maintains an electronic record of transactions local to the fuel station.
2.6 Terminal Network Switch (LAN)	Provides Local Area Network resources to the Terminal and

	Maintenance Operations.
3 Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.
3.1 Compressed Hydrogen Storage Tubes	Compressed hydrogen storage tubes are fixed to tube trailer and store compressed hydrogen for transport.
3.2 Vehicle Cab	The vehicle cab is a self-contained system used to tow hydrogen tube trailers.
3.3 Tube Trailer	The tube trailer is a vehicle towed assembly which holds the compressed hydrogen storage tubes to be transported.
3.4 Vehicle Transport Management Component	The vehicle management component is responsible for managing vehicle subsystems and reporting information about the vehicle system via the transponder
3.4.1 Véhicule Transport Position / Location Unit	Vehicle position / location unit receives position information in the form of broadcasts and beacons from satellite or ground-based systems such as the Global Positioning System or Ground Based Augmentation Systems (GBAS).
3.4.2 Vehicle Transport Tank Sensor	Vehicle tank sensor measures and reports vehicle tank levels using pressure measurements and the known capacity of the tank.
3.4.3 Vehicle Transport Transponder	The vehicle transponder provides communications between the vehicle and Logistics Command Center (LCC). Supports cellular and satellite data communications.
3.5 Vehicle Transport Operator	The Vehicle Transport Operator is responsible for the Vehicle Transport System and picking up and delivering hydrogen as requested by the LCC.
4 Delivery Management System (Logistics Command Center)	The Delivery Management System is responsible for automating the management of the hydrogen supply, conformance to hydrogen fuel standards and maintenance of the Hydrogen Delivery System.
4.1 Supply Management System	The Supply Management System manages the hydrogen supply across the Hydrogen Delivery System.
4.2 LCC Operators	LCC Operators are responsible for managing operations: supply management, maintenance management and compliance management.
4.3 LCC Workstations / Servers (Operations Center)	The LCC Workstations / Servers run management applications and are used by the LCC operators to manage operations.
4.4 LCC Network Switch (LAN)	Provides local area network resources to network enabled systems.
5 Pipeline Distribution System	Compressed H2 distribution pipeline takes gas from the terminal production facilities directly to retail fuel stations.
5.1 Hydrogen Distribution Pump	Connected to the pipeline distribution system at strategic points in order to maintain line pressure within the pipeline system.
5.2 Hydrogen Distribution Pipeline	The compressed H2 distribution pipeline is the network of pipes between terminal production facility and the retail stations. This is typically a smaller pipeline than transmission pipelines employed by current oil refineries. The pipeline material is either a coated metal (to mitigate metal embrittlement) or plastic material which is buried, much like current natural gas distribution lines.
5.3 Bulk Hydrogen Gas Purifier	The bulk hydrogen gas purifier will purify hydrogen which has been temporarily stored in bulk storage prior to the hydrogen entering the
5.4 Production Site Bulk Storage	On-site production bulk storage is used to storage hydrogen gas just produced prior to it being piped to retail stations.

6 Maintenance Systems	Compliance systems are used by systems maintainers in order to measure the system operational performance. This information is used by the maintainer to make repairs to the system or remediate non-conformation to operational requirements.
6.1 System Maintainer	System Maintainer performs maintenance and remediation activities.
6.2 Maintenance Vehicle & Equipment	Maintenance Vehicle and Equipment are employed to maintain and repair the system.
6.3 Maintenance Workstation	Provides a Human-Machine Interface (HMI) to the System Maintainer and performs scheduling planning activities.
6.4 Maintenance Network Switch (LAN)	Provides Local Area Network resources to Maintenance Department / Facility and provides a gateway to the LCC.
6.5 Maintenance Management System	The Maintenance Management System monitors reports and tracks errors, faults, and failures in the system and is used to diagnose, track and close-out problems and manages repair requests made to maintenance personnel.
7 Compliance Systems	
7.1 Calibration Equipment	Calibration Equipment is used to calibrate non-compliance measuring systems.
7.2 Measuring Equipment	Measuring equipment is used by QA personnel to measure the performance of system components and quality of H2 supply.
7.3 Remediation Equipment	Remediation equipment employed to correct non-conforming systems or product (such as H2 purifier to address storage tank impurities).
7.4 Quality Assurance Personnel	Quality Assurance Personnel are required to measure the performance of systems and calibrate metering / measuring equipment.
7.5 Compliance Management System	The Compliance Management System is responsible for measuring and reporting system and hydrogen supply metrics against operational performance requirements.
Additional Step-Out Phase System Components	The Hydrogen Delivery System Step-Out Phase transitions external production to the terminal facilities in order to flatten the distribution network, effectively lowering hydrogen delivery costs by bringing production closer to the retail fuel stations. It also potentially adds pipeline distribution in areas where there are right-of-ways (such as highways) and where there are not urban pressure restrictions. The Hydrogen Delivery System Step-Out Phase will be implemented as the H2 FCV market develops with the key decision point to go forward occurring in 2018, as H2 FCV market adoption starts to ramp up. The Hydrogen Delivery System for the Step-Out phase will be a more scalable and efficient architecture versus the Initial Phase due to the flattening of the distribution network and addition of pipeline distribution, but will require significant capital expenditures to co-locate hydrogen production at the terminals and to build out the pipeline infrastructure. The Hydrogen Delivery System for the Step-Out Phase includes the transport (vehicular and pipeline), storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Hydrogen Delivery System (Initial Phase System)	The Hydrogen Delivery System Initial Phase architecture supports a Centralized Production distribution model. Initial Phase Scenario:

	Production occurs at a large facility and delivered to a terminal facility for delivery to a fuel station. The Hydrogen Delivery System for the Initial Phase includes the transport, storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.

A more detailed version of the Physical Architecture for the system is Appendix B.9: Systems/ Services Interface Diagram (SV-1) and Appendix B.10: System / Services Communications Diagram (SV-2).

Appendix A.3: Function-Form Mapping

Figure 37 is the function-mapping for the system currently maintained within Core v5.0.

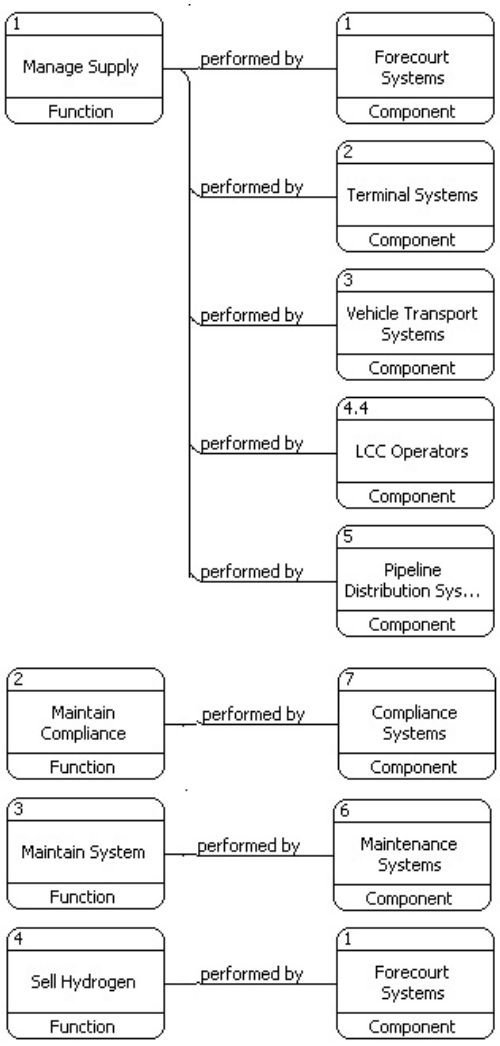

Figure 37. Function-Form Mapping

Appendix A.4: Requirements, Codes, Standards and Regulations

Requirements, Codes, Standards, and Regulations were determined based on characteristic requirements from the QFD, Goals Analysis (performed during the formulation of the Technology Strategy), and research of current agencies and organizations. All Regulations, Codes, Standards and Requirements are maintained in the Core

v5.0 database. All Requirements Traceability is managed and maintained within Core v5.0. Note that some of the Stakeholder Needs and Quality Characteristics are not further refined because they fall out of the scope of the Hydrogen Delivery System. Table 7 contains the prioritized list of Stakeholder Needs.

Table 7. Requirements

Number & Name	Description	refined by
N.1 Safety	The Hydrogen Delivery System shall be safe.	C.7 Minimize Hazardous Byproducts C.14 Minimizes Explosion Risks C.17 Will Minimize H2 Leaks C.18 Support Safety of Maintainers G.1 Factor of Safety G.2 Factor of Toxicity
N.2 High Volume	The Hydrogen Delivery System shall meet high volume demand.	C.12 Adequate Storage Performance G.10 System Delivery Capacity
N.3 Inexpensive	The Hydrogen Delivery System shall employ inexpensive storage, compression methods and technologies and seek to minimize the cost of transporting H2.	G.5 H2 Cost G.11 System Capital Cost
N.4 Adequate Supply	The Hydrogen Delivery System shall deliver an adequate supply of H2 to consumers	C.4 Robust, Reliable System C.5 Scalable System to Meet Demand C.9 Low Cost, High Volume Storage C.12 Adequate Storage Performance C.16 System will be reliable and supportable G.9 Storage Capacity G.10 System Delivery Capacity
N.5 Low Cost Alternative	The Hydrogen Delivery System shall provide hydrogen as a low cost alternative to current vehicle fuels employed today.	G.5 H2 Cost G.11 System Capital Cost
N.6 Less Regulation	The Hydrogen Delivery System shall minimize subjectivity to current and projected regulations	C.11 Compliant with Current Regulations
N.7 Reuse Current Equipment, Infrastructure	The Hydrogen Delivery System shall leverage current investments (capital equipment, infrastructure, processes, and technology).	C.8 Leverage Current Production Processes C.10 Reuses Current Infrastructure
N.8 Efficient	The Hydrogen Delivery System shall maximize energy efficiencies.	C.17 Will Minimize H2 Leaks G.4 Efficiency G.8 Volumetric Density (Kg / L) G.15 Weight G.16 Energy Density
N.9 Low Capital Costs	The Hydrogen Delivery System shall minimize capital costs of components within the system ($ / Kg of H2 delivered).	G.11 System Capital Cost
N.10 Reduce Environmental Impact	The Hydrogen Delivery System shall minimize environmental impact.	C.7 Minimize Hazardous Byproducts C.15 Minimize CO2 Emissions C.19 Utilize non-toxic fuels and materials

		G.2 Factor of Toxicity G.6 Green House Emissions G.7 Pollutants
N.11 Production Safety	The Hydrogen Delivery System shall safety process H2 at terminals and forecourt stations.	C.14 Minimizes Explosion Risks G.2 Factor of Toxicity
N.12 U.S. Energy Resilience	The Hydrogen Delivery System shall improve overall U.S. Energy Resilience.	C.3 Relies on Domestic Energy & Resources C.6 Utilize Alternative Energy Sources
N.13 Low Cost Production	The Hydrogen Delivery System shall rely on efficient, low cost processing and delivery approaches.	C.8 Leverage Current Production Processes G.11 System Capital Cost
N.14 Lower TCO	The Hydrogen Delivery System shall reduce the total TCO of a FCV vehicle over competing technologies by offering low cost hydrogen.	C.2 Low TCO C.13 Modular system supporting upgrades, retrofits G.13 System Maintenance Cost

Table 8 contains the Quality Characteristics derived from the Stakeholder Needs and the corresponding requirement. The characteristic requirements were refined from the system characteristics defined in the QFD

Table 8. Quality Characteristic Requirements

Number & Name	Description	refined by
C.1 Meets Drivers Needs and Behaviors	The Hydrogen Delivery System shall meet the expected needs of operators and maintainers.	G.3 System Availability G.12 Refueling Rate (Kg of H2 / Min) G.17 Cycle Life
C.2 Low TCO	The Hydrogen Delivery System shall achieve energy efficiencies and minimize costs and ultimately Fuel Cell Vehicle (FCV) Total Cost of Ownership for consumers.	G.5 H2 Cost G.11 System Capital Cost G.11.1 Vehicle Transport Capital Cost G.11.2 Large Compressor Capital Costs G.13 System Maintenance Cost
C.3 Relies on Domestic Energy & Resources	The Hydrogen Delivery System shall rely on Domestic Resources (Energy, Materials, and Labor) to operate.	System.1 Domestic Supply Sources
C.4 Robust, Reliable System	The Hydrogen Delivery System shall be robust: - No single point of failure or geographically concentrated infrastructure - Somewhat distributed to minimize impact of natural disasters or attack	G.3 System Availability System.10 System Redundancy / No Single Point of Failure
C.5 Scalable System to Meet Demand	The Hydrogen Delivery System shall scale to meet consumer demand.	System.13 System Scalability

C.6 Utilize Alternative Energy Sources	The Hydrogen Delivery System shall rely on alternative sources of energy to deliver and process H2.	System.1 Domestic Supply Sources
C.7 Minimize Hazardous Byproducts	The Hydrogen Delivery System shall rely on processes and inputs that minimize hazardous waste byproducts during the life of the system.	G.2 Factor of Toxicity
C.8 Leverage Current Production Processes	The Hydrogen Delivery System shall leverage mature, low risk processes as much as possible.	
C.9 Low Cost, High Volume Storage	The Hydrogen Delivery System shall use low cost, high volume storage where feasible.	G.8 Volumetric Density (Kg / L) G.9 Storage Capacity G.10 System Delivery Capacity
C.10 Reuses Current Infrastructure	The Hydrogen Delivery System shall reuse capital equipment and infrastructure as much as feasible.	
C.11 Compliant with Current Regulations	The Hydrogen Delivery System shall be compliant with regulations such that the system may be implemented, operated and maintained.	System.2 Regulations and Codes
C.12 Adequate Storage Performance	The Hydrogen Delivery System shall provide adequate transport and on-site storage to meet consumer demand.	G.8 Volumetric Density (Kg / L) G.15 Weight G.16 Energy Density
C.13 Modular system supporting upgrades, retrofits	The Hydrogen Delivery System shall consist of standards-based, modular components for ease of supportability.	G.13 System Maintenance Cost System.12 Modularity
C.14 Minimizes Explosion Risks	The Hydrogen Delivery System shall utilize technologies to minimize or eliminate the threat of explosion.	G.1 Factor of Safety
C.15 Minimize CO2 Emissions	The Hydrogen Delivery System shall minimize CO2 output by adopting processes which limit the production of CO2 and technology to sequester or capture CO2.	G.6 Green House Emissions
C.16 System will be reliable and supportable	The Hydrogen Delivery System shall be reliable and supportable. .	G.3 System Availability G.17 Cycle Life
C.17 Will Minimize H2 Leaks	The Hydrogen Delivery System shall minimize leaks which may occur in the system.	G.1 Factor of Safety
C.18 Support Safety of Maintainers	The Hydrogen Delivery System shall support the safety of operators and maintainers.	G.1 Factor of Safety

C.19 Utilize non-toxic fuels and materials	The Hydrogen Delivery System shall rely on fuels and materials that are non-toxic as much as feasible.	G.2 Factor of Toxicity

Table 9 lists the Performance Requirements that were derived from the Stakeholder Needs and Characteristic Requirements.

Table 9. Performance Requirements (Goals)

Number & Name	Description
G.1 Factor of Safety	The Hydrogen Delivery System shall have a Factor of Safety comparable to other petro-chemical, gaseous delivery systems.
G.2 Factor of Toxicity	The Hydrogen Delivery System shall minimize the toxicity of fuels, byproducts and materials in the system.
G.3 System Availability	The Hydrogen Delivery system shall be available 99% of the time.
G.4 Efficiency	The H2 Delivery System shall meet or exceed 85% energy efficiency (H2 Output / (H2 Input + Energy Expended)) from production point to dispensing.
G.5 H2 Cost	The H2 Delivery System cost shall not contribute $1.00 / Kg of H2 to the overall retail cost by 2020. {Objective}
G.6 Green House Emissions	The H2 Delivery System shall minimize the release of CO, CO2 during operation and maintenance to less than (TBD) ppm.
G.7 Pollutants	The Hydrogen Delivery System shall minimize the amount of pollutants that are released (TBD ppm) during operation and maintenance.
G.8 Volumetric Density (Kg / L)	The Hydrogen Delivery System shall employ technologies to achieve volumetric densities of 0.035 Kg of H2 / L for vehicle transport.
G.9 Storage Capacity	The Hydrogen Delivery System shall be capable of storing and delivering 1 Kg per H2 FCV vehicle based area market adoption rates.
G.10 System Delivery Capacity	The Hydrogen Delivery System shall be capable of delivering 1500 Kg of H2 per day by 2020.
G.11 System Capital Cost	
G.11.1 Vehicle Transport Capital Cost	The Hydrogen Deliver System shall cost less than $300 / Kg for a H2 transport vehicle.
G.11.2 Large Compressor Capital Costs	The Hydrogen Delivery System shall cost less than $45 / Kg per day for a large compressor.
G.12 Refueling Rate (Kg of H2 / Min)	The dispenser system shall support refueling rates of 2 Kg of H2 / min.
G.13 System Maintenance Cost	The H2 Delivery Costs shall not exceed 3% / year of capital equipment costs.
G.14 Technical Readiness Level	All system components shall meet Technical Readiness Level criteria for a Level 9 rating by 2017 per AFRL TRL v2.2 process.
G.15 Weight	The Hydrogen Delivery System shall be capable of carrying 13.2% H2 by weight for vehicle transport.
G.16 Energy Density	The Hydrogen Delivery System shall be capable of 3.0 KWH / Kg.
G.17 Cycle Life	The Hydrogen Delivery System shall use tanks with TBD cycle-life.

Table 10 contains the Functional Requirement of the system based on the Hydrogen Delivery System functions.

Table 10. Functional Requirements

Number & Name	Description	basis of
F.1 Manage Supply		1 Manage Supply
F.1.1 Store & Transport Hydrogen		1.1 Store & Transport Hydrogen
F.1.1.1 Move Empty Transport		1.1.1 Move Empty Transport
F.1.1.1.1 Move Empty Transport (Dispatch)	Upon receipt of the Dispatch Transport, Delivery Schedule / Confirmation and Delivery Waypoints, the Vehicle Transport Operator shall move the Vehicle Transport to the hydrogen loading site.	1.1.1 Move Empty Transport
F.1.1.1.2 Move Empty Transport (Arrival)	The Vehicle Transport Operator shall issue a Load Request upon arriving at the pickup location.	1.1.1 Move Empty Transport
F.1.1.2 Load Transport		1.1.2 Load Transport
F.1.1.2.1 Load Transport (Activate Load Dispenser)	The Load Dispenser shall be active after receiving Authorize Load.	1.1.2 Load Transport
F.1.1.2.2 Load Transport (Load)	The Vehicle Transport Operator shall load the vehicle transport upon receiving Authorize Load.	1.1.2 Load Transport
F.1.1.2.3 Load Transport (Load Transaction Complete)	Upon receiving the Delivery Conformance Report, Fill Tag and Invoice, the Vehicle Transport Driver shall move the hydrogen to the delivery destination.	1.1.2 Load Transport
F.1.1.2.4 Load Transport (Deactivate Load Dispenser)	The Load Dispenser shall be deactivated after receiving Load Transaction Complete.	1.1.2 Load Transport
F.1.1.2.5 Load Transport (Update Transaction Information)	The System shall send Load Transaction Complete and Metered Amount for each transport loaded.	1.1.2 Load Transport
F.1.1.3 Move Hydrogen	Upon arriving at the delivery destination, the Vehicle Transport Driver shall submit an Unload Request to the facility operator.	1.1.3 Move Hydrogen
F.1.1.4 Unload Transport		1.1.4 Unload Transport
F.1.1.4.1 Unload Transport (Activate Unload Compressor)	The Unload Compressor shall be active after receiving Authorize Unload.	1.1.4 Unload Transport
F.1.1.4.2 Unload Transport (Unload)	The Vehicle Transport Driver shall unload hydrogen from the transport upon receiving Unload Authorization from the facility operator.	1.1.4 Unload Transport

F.1.1.4.3 Unload Transport (Unload Transport Complete)	The Vehicle Transport Operator shall provide the facility operator with the Delivery Conformance Report and provide a Billing Statement / Invoice upon completion of the load.	1.1.4 Unload Transport
F.1.1.4.4 Unload Transport (Deactivate Unload Compressor)	The Unload Compressor shall deactivate upon receiving Unload Transaction Complete.	1.1.4 Unload Transport
F.1.1.4.5 Unload Transport (Update Transaction Information)	The System shall send Unload Transaction Complete and Metered Amount for each transport unloaded.	1.1.4 Unload Transport
F.1.1.5 Monitor Hydrogen Local and Amount		1.1.5 Monitor Hydrogen Location and Amount
F.1.1.5.1 Monitor Hydrogen Location and Amount (Sense and Report H2 Amount)	The Vehicle Transport Management Component shall sense and report H2 Level within the Compressed H2 Tubes.	1.1.5 Monitor Hydrogen Location and Amount
F.1.1.5.2 Monitor Hydrogen Location and Amount (Sense and Report Location)	The Vehicle Transport Management Component shall sense and report the location of the Vehicle Transport.	1.1.5 Monitor Hydrogen Location and Amount
F.1.2 Manage Deliveries		1.2 Manage Deliveries / Pickups / Flow Rates
F.1.2.1 Manage Deliveries (Schedule Delivery)	The Delivery Management System shall schedule deliveries and issue Delivery Schedules and Delivery Waypoints upon receiving a Delivery Request.	1.2 Manage Deliveries / Pickups / Flow Rates
F.1.2.2 Manage Deliveries (Dispatch Transport)	The Delivery Management System shall Dispatch Transports as requested and scheduled .	1.2 Manage Deliveries / Pickups / Flow Rates
F.1.2.3 Manage Deliveries (Consumer Demand Information)	The Delivery Management System shall provide Consumer Demand Information to Producers when requested.	1.2 Manage Deliveries / Pickups / Flow Rates
F.1.2.4 Manage Deliveries (Producer Supply Information)	The Delivery Management System shall request Producer Supply Information as required in order to determine available hydrogen supply on-hand and production capacity at the producer facility.	1.2 Manage Deliveries / Pickups / Flow Rates
F.1.2.5 Manage Deliveries (Set Pipeline Pressure)	The Delivery Management System shall Set Pipeline Pressure based on Operational Performance Information.	1.2 Manage Deliveries / Pickups / Flow Rates
F.1.3 Manage Transactions		1.3 Manage Transactions
F.1.3.1 Manage Transactions (Authorize Load)	The Delivery Management System shall Authorize Load upon the Vehicle Transport Operator providing Vehicle Transport Operator Identification.	1.3 Manage Transactions
F.1.3.2 Manage Transactions	The Delivery Management System	1.3 Manage Transactions

(Authorize Unload)	shall Authorize Unload upon the Vehicle Transport Operator providing Vehicle Transport Operator Identification.	
F.1.3.3 Manage Transactions (H2 Retail Price)	The Delivery Management System shall determine and set the H2 Retail Price.	1.3 Manage Transactions
F.1.3.4 Manage Transactions (Load Transaction Complete)		1.3 Manage Transactions
F.1.3.5 Manage Transactions (Load Transaction Invoice)	The Delivery Management System and Transport Operator shall issue a Load Transaction Invoice / Billing Statement to the Vehicle Transport Operator upon completion of Load Transport.	1.3 Manage Transactions
F.1.3.6 Manage Transactions (Unload Transaction Invoice)	The Delivery Management System shall issue an Unload Transaction Invoice / Billing Statement upon the receipt of the delivered hydrogen.	1.3 Manage Transactions
F.1.4 Monitor Supply Status	The Delivery Management System shall monitor the available supply of hydrogen within the Hydrogen Delivery System.	1.4 Monitor Supply Status
F.1.4.1 Monitor Supply Status (Delivery Request)	The Delivery Management System shall send a Delivery Request when the available on-hand hydrogen supply is low.	1.4 Monitor Supply Status
F.1.4.2 Monitor Supply Status (H2 Loss)	The Delivery Management System shall report H2 Losses based on metered versus measured H2 Level in the system.	1.4 Monitor Supply Status
F.1.4.3 Monitor Supply Status (H2 Supply)	The Delivery Management System shall report the available H2 Supply On-Hand based on H2 Level.	1.4 Monitor Supply Status
F.2 Maintain Compliance		2 Maintain Compliance
F.2.1 Set Performance Thresholds	System Operators and Maintainers shall establish and set Performance Thresholds based on Quality Assurance Goals and Operational Performance Requirements (Corporate).	2.1 Set Performance Thresholds
F.2.2 Perform Conformance Testing	The Quality Assurance Personnel shall conduct conformance testing based on Performance Thresholds.	2.2 Perform Conformance Testing
F.2.2.1 Perform Conformance Testing (Audits)	The System Operators and Maintainers shall support audits and the report all non-conformance or non-compliance findings as a result of an audit.	2.2 Perform Conformance Testing
F.2.2.2 Perform Conformance Testing (Conformance Reports)	The System Maintainers and Quality Assurance Personnel shall test for and report all non-conformance findings	2.2 Perform Conformance Testing

	within the Updated System Conformance Report.	
F.2.2.3 Perform Conformance Testing (Remediation Action)	The System Operators and Maintainers shall issue a Remediation Action Request upon finding non-conformance in the H2 supply or non-complying system equipment.	2.2 Perform Conformance Testing
F.2.3 Remediate Non-Conformance	The System Operators and Maintainers shall send a Maintenance Request if remediation of a non-conformance finding is required.	2.3 Remediate Non-conformance
F.3 Maintain System	Maintenance Management System and Maintenance and Compliance Systems shall monitor and maintain the health of the Hydrogen Delivery System.	3 Maintain System
F.3.1 Monitor and Control System	The Hydrogen Delivery System shall monitor the status of system components, where feasible.	3.1 Monitor System Status
F.3.1.1 Monitor and Control System (Maintenance Request)	The Hydrogen Delivery System Operators and Maintenance Management System shall issue Maintenance Requests upon detecting a system component failure, error or fault where maintenance or repair is required.	3.1 Monitor System Status
F.3.1.2 Monitor and Control System (Recover)	The Maintenance Management System shall attempt to recover the system from detected faults and errors in the system.	3.1 Monitor System Status
F.3.1.3 Monitor and Control System (Facilities Maintenance Request)	System Operators and Maintainers shall make Facilities Maintenance Requests when the condition of company-owned facilities or property affects the operation of the overall system.	3.1 Monitor System Status
F.3.1.4 Monitor and Control System (IT Support)	System Operators and Maintainers shall make IT Support Requests as needed when company-owned Information Technology asset failures affect the overall operation of the system.	3.1 Monitor System Status
F.3.2 Schedule Maintenance		3.2 Schedule Maintenance
F.3.2.1 Schedule Maintenance (New Equipment, Parts)	The Maintenance Management System shall order parts by sending a New Equipment Request as required to support maintenance operations.	3.2 Schedule Maintenance
F.3.2.2 Schedule Maintenance (Dispatch Maintenance Personnel)	The Maintenance Management System shall Dispatch Maintenance Personnel as requested and scheduled.	3.2 Schedule Maintenance
F.3.2.3 Schedule Maintenance (Schedule Maintenance)	The Maintenance Management System shall issue a Maintenance	3.2 Schedule Maintenance

	Schedule based on priority and urgency of maintenance request, available equipment, skilled personnel and tools.	
F.3.3 Perform Maintenance		3.3 Perform Maintenance
F.3.3.1 Perform Maintenance (Repair)	System Maintainers shall perform maintenance and repairs when scheduled and dispatched.	3.3 Perform Maintenance
F.3.3.2 Perform Maintenance (Engineering Change Request)	System Maintainers shall submit Engineering Change Requests as needed to remediate problems due to system design flaws.	3.3 Perform Maintenance
F.4 Sell Hydrogen		4 Sell Hydrogen
F.4.1 Initiate Transaction	The Forecourt System shall activate (Dispenser Activation) the Forecourt Dispenser upon receiving Pre-Authorization and Payment Method Selection.	4.1 Initiate Transaction
F.4.2 Dispense Hydrogen		4.2 Dispense Hydrogen
F.4.2.1 Dispense Hydrogen (Dispense)	The Forecourt System shall dispense hydrogen and meter hydrogen output upon receiving Dispenser Activation.	4.2 Dispense Hydrogen
F.4.2.2 Dispense Hydrogen (Metered Amount Dispensed)	The Forecourt System shall output the H2 Amount Dispensed.	4.2 Dispense Hydrogen
F.4.3 Complete Transaction	The Forecourt System shall calculate and send Competed Point-of-Sale Information and Customer Receipt upon receiving Dispenser Deactivation.	4.3 Complete Transaction

Table 11 contains the System-Wide Requirements for the system.

Table 11. System-Wide Requirements

Number & Name	Description
System.1 Domestic Supply Sources	The Hydrogen Delivery System shall rely on domestic sources of energy feedstocks, domestic suppliers and equipment and components built from domestic material sources as much as feasible.
System.2 Regulations and Codes	The Hydrogen Delivery System shall be compliant with all federal, state and local regulations and codes.
System.3 Monitor System	The Hydrogen Delivery System shall provide mechanisms to monitor the state and health of the system.
System.4 Control System	The Hydrogen Delivery System shall provide mechanisms to operate and recover from warnings, errors and faults.
System.5 Report System Component Status	The Hydrogen Delivery System component shall report all warnings, errors, faults and failures that could impact the operation and maintenance of the system.
System.6 Report System Status	The Hydrogen Delivery System shall report outages as required to agencies, fuel stations, terminals and production facilities.
System.7 Meter Hydrogen Supply	The Hydrogen Delivery System shall measure the dispensing and storage of all hydrogen fuels within the system.
System.8 Operational Availability	The system shall be operationally available 99% of the time.
System.9 Degraded Operation	The system shall be capable of operating in a degraded fashion in the presence of errors, faults and failures.
System.10 System Redundancy / No Single Point of Failure	The system shall be designed with redundant hydrogen energy delivery and communications pathways and redundant operational systems to avoid single points of failure.
System.11 System Fault Tolerance	The H2 Delivery System shall recover from errors and faults detected in subsystems.
System.12 Modularity	The Hydrogen Delivery System shall employ subsystems, components and assemblies which are standards-based, modular components with physical, functional and logical standard interfaces.
System.13 System Scalability	The Hydrogen Delivery System shall be design to scale in a manner which is cost effective and advantageous to meeting operational cost requirements.

An extensive search was conducted in order to identify all of the Federal, State and Local Regulations that impact the Hydrogen Delivery System. These regulations can be found in Table 12.

Table 12. Regulations

Number & Name	Description
Reg.1 Hydrogen and Fuel Cells Permitting Guide (DOE)	The Hydrogen Delivery System shall comply with the "Hydrogen and Fuel Cells Permitting Guide" (DOE) http://www.fuelcellstandards.com/permittingguide.htm
Reg.2 Hydrogen Safety (OHSA 29 CFR 1910.103)	The Hydrogen Delivery System shall comply with the Hydrogen Safety (OHSA 29 CFR 1910.103) http://www.fuelcellstandards.com/permittingguide.htm
Reg.3 Hydrogen Fuel Standards (State of California)	The Hydrogen Delivery System shall comply with the Hydrogen Fuel Standards (State of California) http://www.fuelcellstandards.com/california%20hydrogen%20fuel%20standard.htm
Reg.4 Compressed Gases (OHSA 29 CFR 1910.101)	The Hydrogen Delivery System shall comply with the Compressed Gases (OHSA 29 CFR 1910.101) http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9747
Reg.5 Process Safely Management of Highly Hazardous Materials (OHSA 29 CFR 1910.119)	The Hydrogen Delivery System shall comply with the Process Safely Management of Highly Hazardous Materials (OHSA 29 CFR 1910.119) http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760
Reg.6 Regulation of Electric Utilities Engaged in Interstate Commerce (FERC 16USC824)	The Hydrogen Delivery System shall comply with the Regulation of Electric Utilities Engaged in Interstate Commerce (FERC 16USC824) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+16USC824
Reg.7 Commercial Motor Vehicle Safety (DOT 49USC31136)	The Hydrogen Delivery System shall comply with the Commercial Motor Vehicle Safety (DOT 49USC31136) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+49USC31136
Reg.8 Commercial Motor Carrier Safety (DOT 49USC31502(b))	The Hydrogen Delivery System shall comply with the Commercial Motor Carrier Safety (DOT 49USC31502(b)) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+49USC31502
Reg.9 Transportation of Hazardous Material (DOT 49USC5101)	The Hydrogen Delivery System shall comply with the Transportation of Hazardous Material (DOT 49USC5101) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+49USC5101
Reg.10 Other Regulations Relating to Transportation (DOT 49 CFR Ch.I (10-1-2005))	The Hydrogen Delivery System shall comply with the Other Regulations Relating to Transportation (DOT 49 CFR Ch.I (10-1-2005)) http://www.access.gpo.gov/nara/cfr/waisidx_05/49cfrv2_05.html
Reg.11 Transportation Rail Programs Safety (DOT 49USC20101)	The Hydrogen Delivery System shall comply with the Transportation Rail Programs Safety (DOT 49USC20101) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+49USC20101
Reg.12 Other Regulations Relating to Transportation (DOT 49 CFR Ch.II (10-1-2005))	The Hydrogen Delivery System shall comply with the Other Regulations Relating to Transportation (DOT 49 CFR Ch.II (10-1-2005)) http://www.access.gpo.gov/nara/cfr/waisidx_05/49cfrv4_05.html
Reg.13 Transportation Pipeline Safety (DOT 49USC60101)	The Hydrogen Delivery System shall comply with the Transportation Pipeline Safety (DOT 49USC60101) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+49USC60101
Reg.14 Transportation by Pipeline (DOT 2005 CFR Title 49, Volume 3)	The Hydrogen Delivery System shall comply with the Transportation by Pipeline (DOT 2005 CFR Title 49, Volume 3) http://www.access.gpo.gov/nara/cfr/waisidx_05/49cfr192_05.html
Reg.15 Navigation and Navigable Waters (USCG 33USC1221)	The Hydrogen Delivery System shall comply with the Navigation and Navigable Waters (USCG 33USC1221) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+33USC1221

Reg.16 Navigation and Navigable Waters (USCG 33USC1236)	The Hydrogen Delivery System shall comply with the Navigation and Navigable Waters (USCG 33USC1236) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+33USC1236
Reg.17 Maritime Safety (DOT, USCG 46 CFR)	The Hydrogen Delivery System shall comply with the Maritime Safety (DOT, USCG 46 CFR) http://www.access.gpo.gov/cgi-bin/cfrassemble.cgi?title=200546
Reg.18 Navigation and Navigable Waters (USCG, USACE 33 CFR)	The Hydrogen Delivery System shall comply with the Navigation and Navigable Waters (USCG, USACE 33 CFR) http://www.access.gpo.gov/cgi-bin/cfrassemble.cgi?title=200533
Reg.19 Other Regulations Relating to Transportation (USCG 49 CFR)	The Hydrogen Delivery System shall comply with the Other Regulations Relating to Transportation (USCG 49 CFR) http://www.access.gpo.gov/nara/cfr/waisidx_05/49cfrv2_05.html
Reg.20 Transportation of Hazardous Material (USCG 49 USC)	The Hydrogen Delivery System shall comply with the Transportation of Hazardous Material (USCG 49 USC) http://www.access.gpo.gov/uscode/title49/subtitleiii_chapter51_.html
Reg.21 Carriage of Liquid Bulk Dangerous Cargoes (USCG 46 USC)	The Hydrogen Delivery System shall comply with the Carriage of Liquid Bulk Dangerous Cargoes (USCG 46 USC) http://www.access.gpo.gov/uscode/title46/subtitleii_partb_chapter37_.html
Reg.22 Navigation and Navigable Waters (USCG 46 USC 1228)	The Hydrogen Delivery System shall comply with the Navigation and Navigable Waters (USCG 46 USC 1228) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+33USC1228
Reg.23 Navigation and Navigable Waters (USCG 46 USC 1221)	The Hydrogen Delivery System shall comply with the Navigation and Navigable Waters (USCG 46 USC 1221) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+33USC1221
Reg.24 Navigation and Navigable Waters (USCG 46 USC 1236)	The Hydrogen Delivery System shall comply with the Navigation and Navigable Waters (USCG 46 USC 1236) http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+33USC1236
Reg.25 Storage and Handling of Gaseous and Liquefied Hydrogen Systems (State of Michigan R 29 7001 – R 29 7126)	The Hydrogen Delivery System shall comply with the Storage and Handling of Gaseous and Liquefied Hydrogen Systems (State of Michigan R 29 7001 – R 29 7126) http://www.fuelcellstandards.com/Michigan.htm

An extensive search was conducted to find Codes & Standards applicable to the Hydrogen Delivery System. These Codes & Standards have been developed by U.S. and European codes & standards bodies. These Codes & Standards can be found in Table 13.

Table 13. Codes & Standards

Number & Name	Description	governs
Std.1 Safety / General Design	This section contains codes and standards which apply to safety and the general design of hydrogen systems.	7.4 Quality Assurance Personnel
Std.1.1 Hydrogen Fueling Station Codes and Standards (DOE)	http://www.fuelcellstandards.com/hydrogenfuelingstation.htm	1 Forecourt Systems 6 Maintenance Systems
Std.1.2 International Fire Code (ICC)	Storage & Design http://www.fuelcellstandards.com/2.1.5.htm Applies to bulk storage and fuel systems, fuel stations	1.1 Forecourt Compressed Hydrogen Storage System 1.2 Forecourt Compressed Hydrogen Dispenser 2.1 Terminal Compressed Hydrogen Dispenser 2.2 Terminal Compressed Hydrogen Storage System
Std.1.3 Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks: Chapter 10 Gaseous Hydrogen Systems (NFPA 55)	http://www.fuelcellstandards.com/2.1.6.1.htm	1 Forecourt Systems 2 Terminal Systems 3 Vehicle Transport Systems 6 Maintenance Systems
Std.1.4 Canadian Hydrogen Installation Code (CAN/BNQ 1784)	http://www.fuelcellstandards.com/2.2.htm	6 Maintenance Systems
Std.1.5 Installation Standard for Bulk Hydrogen Supply Systems (CGA Publication H5)	http://www.fuelcellstandards.com/2.1.2.20.htm	1.1 Forecourt Compressed Hydrogen Storage System 2.2 Terminal Compressed Hydrogen Storage System
Std.1.6 Hydrogen Technologies (NFPA 2)	http://www.fuelcellstandards.com/2.1.6.2.htm	Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.2 Tanks & Storage	Codes and standards which apply to storage systems.	7.4 Quality Assurance Personnel
Std.2.1 Boiler & Pressure Vessel Code (ASME BPVC Section VIII)	http://www.fuelcellstandards.com/2.1.3.htm	1.1 Forecourt Compressed Hydrogen Storage System 2.2 Terminal Compressed Hydrogen Storage System
Std.2.2 Adjacent Storage of Compressed Hydrogen and Other Flammable Gases (CGA Publication PS21)	http://www.fuelcellstandards.com/2.1.2.15.htm	1.1 Forecourt Compressed Hydrogen Storage System 2.2 Terminal Compressed Hydrogen Storage System
Std.2.3 Use of Carbon Fiber Fully Wrapped Composite Storage Vessels Permanently Installed in Stationary Gaseous Hydrogen Fueling Systems (CGA Publication PS26)	http://www.fuelcellstandards.com/2.1.2.18.htm	1.1.1 Forecourt Storage Compressor 2.2 Terminal Compressed Hydrogen Storage System

Std.2.4 Use of LPG or Propane Tank as Compressed Hydrogen Storage Buffers (CGA Publication PS33)	http://www.fuelcellstandards.com/PS33.htm	1.1 Forecourt Compressed Hydrogen Storage System 2.2 Terminal Compressed Hydrogen Storage System
Std.2.5 Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks Chapter 10 Gaseous Hydrogen Systems (NFPA 55)	http://www.fuelcellstandards.com/2.1.6.1.htm	1.1 Forecourt Compressed Hydrogen Storage System 2.2 Terminal Compressed Hydrogen Storage System 3.1 Compressed Hydrogen Storage Tubes
Std.2.6 Boiler and Pressure Vessel Code Section XII-Transportation Tanks (ASME BPVC Section VIII)	http://www.fuelcellstandards.com/2.1.3.htm	3.1 Compressed Hydrogen Storage Tubes
Std.3 Embrittlement Tests	Standards for testing material for hydrogen embrittlement.	7.4 Quality Assurance Personnel
Std.3.1 Standard Test Method for Electronic Measurement for Hydrogen Embrittlement from Cadmium-Electroplating Processes (ASTM F326-96 / WK10222)	http://www.fuelcellstandards.com/2.3.2.htm	5 Pipeline Distribution System 6 Maintenance Systems
Std.3.2 Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating Processes and Service Environments (ASTM F519-08)	http://www.fuelcellstandards.com/2.3.2.htm	5 Pipeline Distribution System 6 Maintenance Systems
Std.3.3 Standard Test Method for Electrochemical Measurement of Diffusible Hydrogen in Steel (ASTM F1113-87 / WK 6483)	http://www.fuelcellstandards.com/2.3.2.htm	5 Pipeline Distribution System 6 Maintenance Systems
Std.3.4 Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (ASTM F1459-06)	http://www.fuelcellstandards.com/2.3.2.htm	5 Pipeline Distribution System 6 Maintenance Systems
Std.3.5 Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique (ASTM F1624-06)	http://www.fuelcellstandards.com/2.3.2.htm	5 Pipeline Distribution System 6 Maintenance Systems
Std.3.6 Standard Terminology Relating to Hydrogen Embrittlement (ASTM F2078-01 / WK12962)	http://www.fuelcellstandards.com/2.3.2.htm	5 Pipeline Distribution System 6 Maintenance Systems
Std.4 Piping & Pipelines	Standards related to piping hydrogen and hydrogen pipeline general safety and design.	7.4 Quality Assurance Personnel
Std.4.1 Piping and Pipelines (ASME B31 Series)	http://www.fuelcellstandards.com/2.1.2.htm	5 Pipeline Distribution System
Std.4.2 Hydrogen Piping Systems at Consumer Locations	http://www.fuelcellstandards.com/2.1.2.3.htm	5 Pipeline Distribution System

(CGA Publication G5.4)		
Std.4.3 Hydrogen Pipeline Systems (CGA Publication G5.6)	http://www.fuelcellstandards.com/2.1.2.11.htm	5 Pipeline Distribution System
Std.4.4 Hydrogen Piping and Pipelines (ASME B31.12)	http://www.fuelcellstandards.com/2.1.2.htm	5 Pipeline Distribution System
Std.4.5 High Pressure Hydrogen Piping Systems at Consumer Locations (CGA Publication G5.8)	http://www.fuelcellstandards.com/2.1.2.19.htm	5 Pipeline Distribution System
Std.4.6 Carbon Monoxide and Syngas Pipeline Systems (CGA Publication G5.7 (EIGA Doc 120/04))	http://www.fuelcellstandards.com/G57.htm	5 Pipeline Distribution System
Std.5 Hydrogen Vent Systems (CGA Publication G5.5)	http://www.fuelcellstandards.com/2.1.2.4.htm	7.4 Quality Assurance Personnel Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.6 Fuel Station Design	Codes and Standards related to the design of the fuel station and related system components.	7.4 Quality Assurance Personnel
Std.6.1 Airport Hydrogen Fuelling Facility Operation (ISO/PAS 15594)	http://www.fuelcellstandards.com/1.2.4.htm	1 Forecourt Systems
Std.6.2 Gaseous Hydrogen - Service Stations (Working Group #11 / ISO TS 20100)	http://www.fuelcellstandards.com/1.2.11.htm	1 Forecourt Systems
Std.6.3 Refueling Station (European Integrated Hydrogen Project (EIHP) - Work Package 2)	http://www.fuelcellstandards.com/3.3.htm	1 Forecourt Systems
Std.7 Dispensing Equipment	Codes and Standards which apply to dispensing systems.	7.4 Quality Assurance Personnel
Std.7.1 Compressed Hydrogen Vehicle Fueling Connection Devices (SAE J2600)	http://www.fuelcellstandards.com/2.1.7.2.htm	1.2 Forecourt Compressed Hydrogen Dispenser
Std.7.2 Vehicle Fuel Systems Code (NFPA 52)	http://www.fuelcellstandards.com/2.1.6.6.htm	1.2 Forecourt Compressed Hydrogen Dispenser
Std.7.3 Compressed Hydrogen Surface Vehicle Refueling Connection Devices (ISO 17268)	http://www.fuelcellstandards.com/1.2.5.htm	1.2 Forecourt Compressed Hydrogen Dispenser
Std.7.4 Compressed Hydrogen Vehicle Fueling Communication Devices (SAE J2601)	http://www.fuelcellstandards.com/2.1.7.2.htm	
Std.7.5 70 MPa Compressed Hydrogen Surface Vehicle Refueling Connection Device and Optional Vehicle to Station Communication (SAE J2799 - TIR)	http://www.fuelcellstandards.com/2.1.7.2.htm	1.2 Forecourt Compressed Hydrogen Dispenser
Std.7.6 Fuel Dispensing for	http://www.fuelcellstandards.com/2.1.3.10.htm	1.2 Forecourt Compressed Hydrogen

Hydrogen Gas Powered Vehicles (CSA America HGV4)		Dispenser
Std.7.7 Hydrogen Gas Meter Code (USA National Institute of Standards and Technology (NIST) Weights and Measures Division)	http://www.fuelcellstandards.com/2.10.1.htm	1.2 Forecourt Compressed Hydrogen Dispenser
Std.7.8 Compressed Gaseous Fuel Measuring Systems for Vehicles (OILM R 139)	http://www.fuelcellstandards.com/oilmr139.htm	1.2 Forecourt Compressed Hydrogen Dispenser
Std.7.9 Refueling Interface (European Integrated Hydrogen Project (EIHP) - Work Package 3)	http://www.fuelcellstandards.com/3.3.htm	1.2 Forecourt Compressed Hydrogen Dispenser
Std.8 Hydrogen Detection	Codes and standards related to the detection of hydrogen (leaks, closed areas).	7.4 Quality Assurance Personnel
Std.8.1 Gas and Vapor Detectors and Sensors (ANSI/UL 2075)	http://www.fuelcellstandards.com/2.1.9.2.htm	Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.8.2 Equipment for Explosive Atmospheres (ISA 12.13.01)		Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.8.3 Electrical Apparatus for the Detection and Measurement of Flammable Gases- Part 1. General Requirements and Test Methods (IEC 61779-1)	http://www.fuelcellstandards.com/1.1.20.htm	Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.8.4 Electrical Apparatus for Explosive Gas Atmospheres: Part 29-1 Electrical apparatus for the detection and measurement of flammable gases - General Requirements and Test Methods (IEC 60079-29-1)	http://www.fuelcellstandards.com/1.1.20.htm	Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.8.5 Electrical Apparatus for Explosive Gas Atmospheres: Part 29-2 Electrical apparatus for the detection and measurement of flammable gases - Guide for the selection, installation, use and maintenance (IEC 60079-29-2)	http://www.fuelcellstandards.com/1.1.20.htm	Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.8.6 Hydrogen Detector Apparatus (ISO TC197 Working Group #13 / ISO 26142)	http://www.fuelcellstandards.com/1.2.13.htm	Additional Step-Out Phase System Components Hydrogen Delivery System (Initial Phase System)
Std.9 Properties	Documented properties of hydrogen.	7.4 Quality Assurance Personnel
Std.9.1 Standard Density Data, Atmospheric Gases & Hydrogen (CGA Publication P6)		

Std.9.2 Hydrogen (CGA Publication G-5)		
Std.10 General Safety	Standards and guidance related to general hydrogen safety.	7.4 Quality Assurance Personnel
Std.10.1 Guide to Safety of Hydrogen and Hydrogen Systems (AIAA G-095)	http://www.fuelcellstandards.com/1.2.12.htm	1.3 Fuel Station Operator 2.3 Terminal Operator 3.5 Vehicle Transport Operator 6.1 System Maintainer
Std.10.2 Basic Considerations for the Safety of Hydrogen Systems (ISO TR 15916)	http://www.fuelcellstandards.com/3.1.htm	1.3 Fuel Station Operator 2.3 Terminal Operator 3.5 Vehicle Transport Operator 6.1 System Maintainer
Std.10.3 Safety (European Integrated Hydrogen Project (EIHP) - Work Package 5)	http://www.fuelcellstandards.com/2.3.htm	1.3 Fuel Station Operator 2.3 Terminal Operator 3.5 Vehicle Transport Operator 6.1 System Maintainer
Std.11 Fuel Standards	Standards relating to hydrogen energy.	7.4 Quality Assurance Personnel
Std.11.1 Commodity Specification for Hydrogen (CGA Publication G5.3)	http://www.fuelcellstandards.com/2.1.2.2.htm	6 Maintenance Systems 2 Maintain Compliance
Std.11.2 Hydrogen Fuel - Product Specification, Part 2: PEM fuel cell applications for road vehicles (ISO/TS 14687-2)	http://www.fuelcellstandards.com/1.2.12.htm	6 Maintenance Systems 2 Maintain Compliance
Std.11.3 Hydrogen Quality Guideline for Fuel Cell Vehicles (SAE J2719)	http://www.fuelcellstandards.com/2.1.7.2.htm	6 Maintenance Systems 2 Maintain Compliance
Std.11.4 Expert Watch Group on Fuels for Fuel Cells (CEN/TC19)	http://www.fuelcellstandards.com/3.1.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12 Contaminant Tests	Codes and Standards related to contamination testing.	7.4 Quality Assurance Personnel
Std.12.1 Standard Test Method for Determination of Trace Contaminants in Hydrogen and Related Fuel Cell Feed Gases (ASTM WK4548)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12.2 Standard Practice for Sampling of High Pressure Hydrogen and Related Fuel Cell Feed Gases (ASTM WK 5847)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12.3 Standard Test Method for Ion Selective Electrode or Ion Chromatography Based Determination of Ammonia in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK6527)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12.4 Standard Test Method for Determination of Formaldehyde and Other	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance

Carbonyl Compounds in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK6624)		
Std.12.5 Standard Test Method for Determination of Ammonia in Hydrogen and Other Fuel Cell Feed Gases by Gas Chromatography and Nitrogen Chemiluminescence Detection (ASTM WK8150)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12.6 Standard Test Method for Ion Chromatography Based Determination of Cations in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK9211)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12.7 Standard Test Method for Determination and Sampling of Particulate Matter in High Pressure Hydrogen Used as a Gaseous Fuel with an In-Stream Filter (ASTM WK9688)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12.8 Standard Test Method for Determination of Ammonia and Trace Water in Hydrogen and Other Fuel Cell Gaseous Fuels by Infrared Spectroscopy (ASTM WK10196)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.12.9 Standard Test Method for Determination of Trace Hydrogen Sulfide, Methyl Mercaptan and Carbonyl Sulfide in Hydrogen Fuel (ASTM WK18779)	http://www.fuelcellstandards.com/2.3.htm	6 Maintenance Systems 2 Maintain Compliance
Std.13 Terminology Associated with Hydrogen Fuel Technologies (CGA Publication H4)	http://www.fuelcellstandards.com/2.1.2.13.htm	7.4 Quality Assurance Personnel

Appendix A.5: Architecture Development

Team Hydrogen developed architectures of the Hydrogen Delivery System using the Department of Defense Architecture Framework (DoDAF) version 1.5.

Appendix A.5.1: DoDAF Development Process

Figure 38 illustrates the DoDAF development process followed by the Hydrogen Team as specified in the DoDAF Architecture Framework (DoDAF) version 1.5.

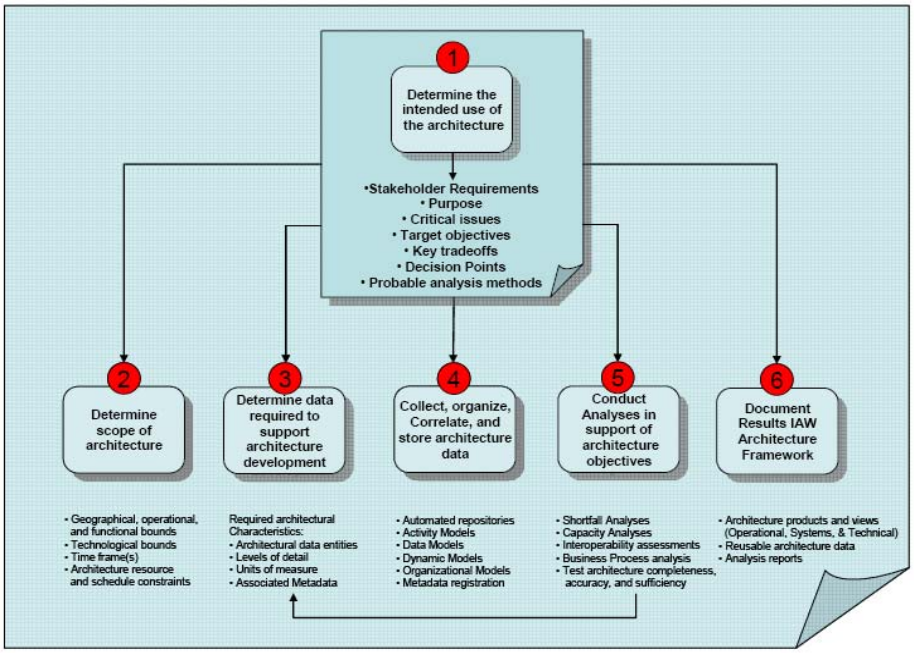

Figure 38. DoDAF Development Process

Appendix A.5.2: DoDAF Methodology

Figure 39 illustrates the methodology followed in the development of the DoDAF v1.5 Architecture for the Hydrogen Delivery System.

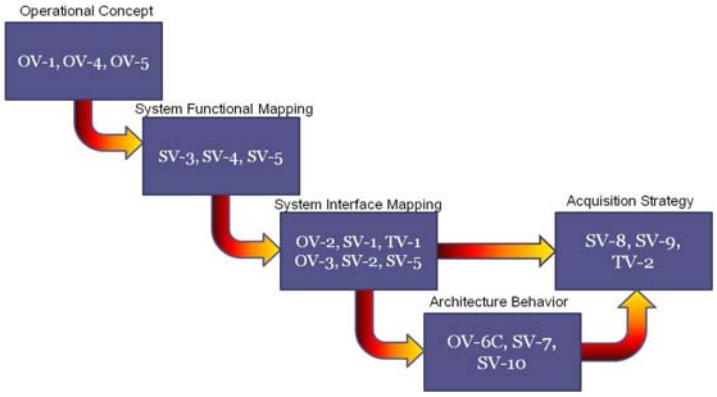

Figure 39. DoDAF Methodology [7]

Appendix A.6: Stakeholder Goals Analysis

Appendix A.6.1: Goals Analysis Overview

We isolated goals specific to a Hydrogen Delivery System which link back to Stakeholder Needs and System Characteristics identified earlier:

- The DOE has developed and refined goals and target from many of the high-level stakeholder needs which we have identified.

[7] Levis, A., "Modeling and Simulation for Architecture Assessment", Slide 24 (Navy's ASN (RDA Cheng Approach), 4/20/2004, HQ Air Force

- Additional goals were derived from other needs not identified by the DOE

Though needs were scored by our project during earlier analysis, we will need to go through a second scoring exercise in order to rank order the goals for later architecture alternative analysis. The method used will be similar to stakeholder needs analysis. The final score will be validated against earlier results from the Stakeholder Needs Analysis.

Appendix A.6.2: Goals Analysis Conclusions

The results of the scoring and ranking of the Goals and ranking of the stakeholders can be found in Figure 40. We drew the following conclusions from those results:

- Safety, Toxicity, Availability, Efficiency and Cost are the top goals for the system
- Cycle-Life, Energy Density and Weight were the lowest scoring goals
- It's not a surprise that Government Policy Makers are the highest ranked stakeholder, since many of these goals were introduced by Government Organizations, such as the DOE, DOT
- As expected, Vehicle Manufacturers moved up to 2nd since the distribution state and goals directly impact their system versus many of the other stakeholders. As a result, architecture alternatives analysis and development requires close participation with these stakeholders.
- Government Regulations and Environmentalists fall down the list. The impact of regulation is felt in terms of constraints (limits for tube trailers (DOT), pipeline infrastructure)

The result of this analysis was to establish ranked goals and stakeholders which factored into the architecture selection process. First, we used the ranking of the stakeholders by goal to focus on key technology alternatives that must be evaluated and selected. Later, we used the goal scores from this analysis to weight the scoring of the key technologies during the architecture selection process.

Stakeholder Goals Analysis

		Column #	1	2	3	4	6	7	8	9	10		
		Relative Weight (Order Ranking, Highest = Best)	1	0.962	0.885	0.859	0.744	0.705	0.654	0.487	0.321		
Row #	Relative Weight (Order Ranking, Highest = Best)	Stakeholder Goals \ Relevant Stakeholders	Government Policy	Vehicle Manufacturer	Equipment Manufacturer	Distributor	Producer	Vehicle Owner	Retailer	Government Regulators	Environmental Interest Groups		Goals Score
1	1	Factor of Safety	5	5	5	5	5	5	5	5	5		1
2	0.911	Factor of Toxicity of Fuels, Byproducts, Materials	5	4	4	5	3	5	5	5	5		0.819
3	0.844	System Availability	5	5	5	5	5	5	5	3	0		0.779
4	0.867	Efficiency (% H2 Energy Conserved)	5	2	5	5	5	2	5	5	5		0.736
5	0.778	H2 Cost ($ / Kg H2 or $ / GGE)	5	5	5	5	5	5	5	0	0		0.683
6	0.733	Green House Gas Emissions (ppm)	5	5	5	0	5	3	0	5	5		0.534
7	0.733	Pollutants (ppm)	5	5	5	0	5	3	0	5	5		0.534
8	0.689	Volumetric Density (Kg / L)	5	5	4	5	3	3	3	3	0		0.529
9	0.689	Storage Capacity (Kg of H2 Total)	5	5	2	5	3	5	3	3	0		0.522
10	0.644	Delivery System Capacity (Kg H2 / day)	5	5	2	5	5	2	5	0	0		0.473
11	0.644	System Capital Cost	5	2	5	5	5	2	5	0	0		0.468
12	0.6	Refueling Rate (Kg of H2 / Min)	3	5	5	2	2	5	5	0	0		0.403
13	0.578	System Maintenance Cost	2	2	5	5	5	2	5	0	0		0.367
14	0.489	Technical Readiness Level	5	5	5	5	2	0	0	0	0		0.296
15	0.444	% of H2 by Weight	5	5	2	5	0	1	0	2	0		0.236
16	0.422	Energy Density (KWH / L)	5	5	0	5	0	2	0	2	0		0.21
16	0.4	Cycle Life (Cycles 1/4 tank to full)	3	5	5	0	0	5	0	0	0		0.191

Need Ranking	
0	Not used
1	Not useful
2	Useful to some extent
3	Satisfactory
4	Good
5	Excellent

Figure 40. Stakeholder Goals Analysis with Goals, Stakeholder Rankings

Relative weighting of the stakeholders is the sum of the column scores (total score) divided by the max score out of all of the stakeholders (Producer). Relative weighting of the Stakeholder Goals is the sum of the row scores divided by the max score of all of the needs (Safety in the storage, transport and use of fuels. The Goals Score is the sum of (each row score * Stakeholder Relative Weighting * Stakeholder Goal Relative Weighting).

Appendix A.7: Program Risks

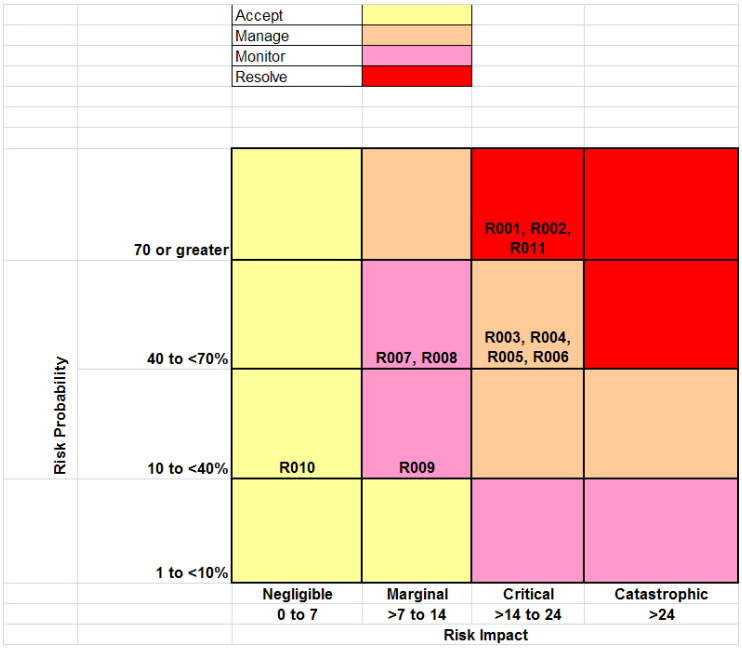

Figure 41. Risk Radar Assessment

Table 14. Program Risk Register

Risk Identifier	Risk Category	Risk Description	Mitigation Strategy	Date Risk Identified	Status	Schedule Impact	Cost Impact	Performance Impact	Overall Risk Importance	Probability
R001	Cost	2640 PSI regulatory limit on Compressed H2 vehicle transport results in negative NPV	Influence DOT and legislation to increase vehicle transport pressures for hydrogen to 5 k psi or 10 k psi. Introduce new technologies such as cryo-cooling to increase tank capacities.	12-Oct-08	Active	0	8	10	18	75 %
R002	Cost	150 PSI limit on Pipeline transport of Compressed H2, severely limiting transmission and distribution lines.	Distribution by vehicle transport will be required, particularly within urban areas. Influence regulations to increase pipeline pressures, particularly in cases where pipeline transmission or distribution is more cost effective and feasible.	12-Oct-08	Active	0	4	10	14	75 %
R003	Technical	5 K, 10K PSI Compressed H2 Trailers not mature.	Limits energy densities. Prevents us from meeting goals. Currently 5 K PSI prototype tubes exist. 10 K PSI tubes are in R&D phase. Can mitigate by exploring the use of cryo-compressed H2, or using Liquid H2.	17-Oct-08	Active	0	8	10	18	50 %

R004	Cost / Schedule	Lack of H2 FCV adoption (for various reasons)	Partner with a H2 gas producer and distributor (Praxair, Air Products, and Air Liquide) to share risk and limit capital costs in building out initial systems. Come up with a plan to merge with or step-out of partnership as market adoption increases enough to justify the capital expenditure.	26-Oct-08	Active	5	8	5	18	50%
R011	Cost	Volatility in Gasoline, Diesel, Ethanol Prices impact price Hydrogen can be sold, affecting NPV	Risk is in planning process.	30-Nov-08	Plan	0	10	5	15	100%
R005	Resource Management	Lack of experts in H2 distribution, equipment, systems	Partner with a H2 gas producer and distributor (Praxair, Air Products, Air Liquide) and leverage their knowledge and expertise. Come up with a plan to merge with or step-out of partnership as market adoption increases enough to justify the capital expenditure and hiring of subject matter experts.	26-Oct-08	Managing	5	8	5	18	50%
R006	Schedule	Aggressive Schedule	Monitor progress closely with metrics to determine any slips. Create multiple parallel activities and ensure adequate float. Make adjustments as required.	2-Oct-08	Managing	5	10	0	15	50%
R007	Technical	Unfamiliar Design Elements	Leverage expertise of partners and involve stakeholders	2-Oct-08	Managing	3	4	5	12	40%
R008	Technical, Schedule	Creeping Requirements, Undefined Project Expectations	Maintain and monitor Requirements Traceability Matrix, Schedule and Design Specs. Monitor schedule for impacts.	2-Oct-08	Managing	5	4	3	12	60%
R009	Resource Management	Untrained Operators, Maintenance Personnel	Provide personnel with adequate upfront and ongoing training. Design system with the operator and maintainer in mind.	26-Oct-08	Ongoing	3	4	5	12	10%
R010	Customer	Meeting Requirements and Expectations	Identify any potential confusion upfront with all stakeholders. Set up communication channels between all stakeholders. Work with stakeholders to manage expectations, ensure customer satisfaction, and ensure buy-in by using prototyping. Hold monthly meetings with key stakeholders to ensure customers understanding of progress.	2-Oct-08	Managing	3	2	0	5	10%

Appendix A.8: Tree Diagram

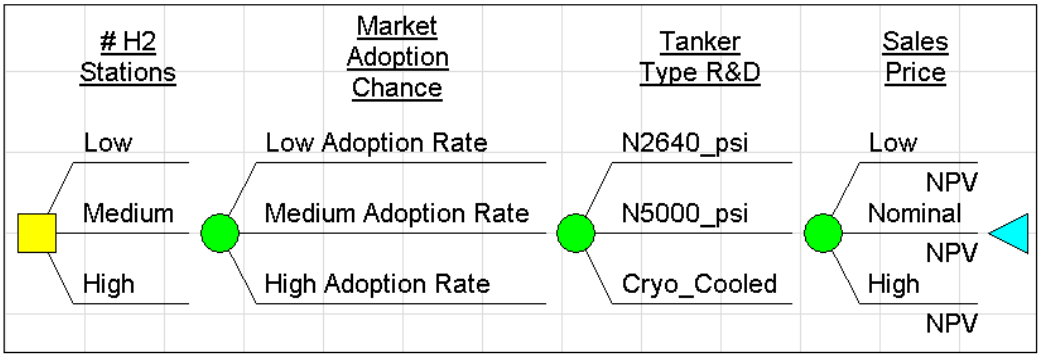

Figure 42. Tree Diagram

Appendix A.9: Expected H2 Adoption Scenarios

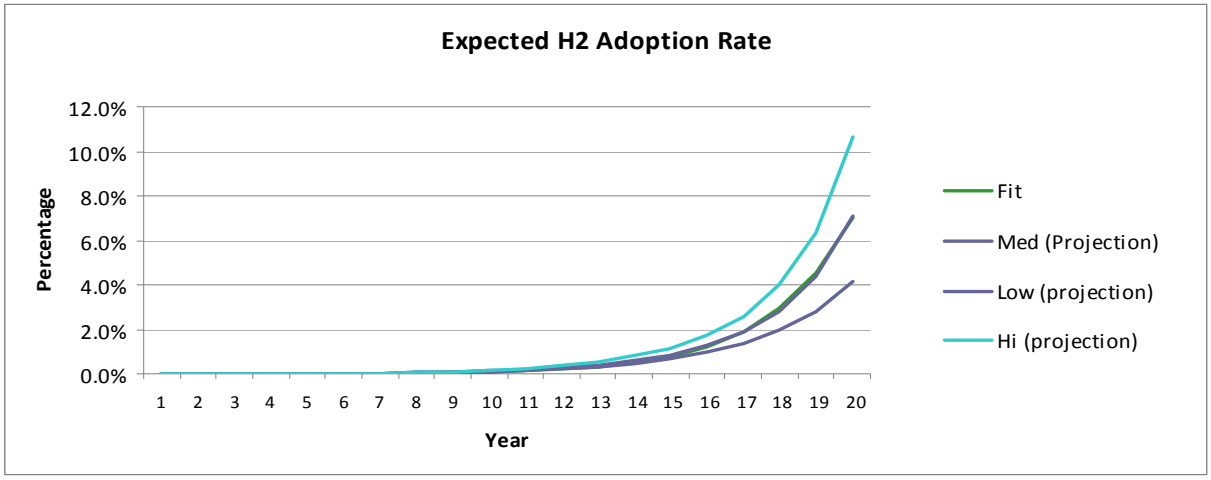

Figure 43. Expected H2 Adoption Scenarios

Appendix B: DoDAF v1.5 Architecture Framework Process Artifacts

Appendix B.1: Hydrogen Delivery System Initial Phase Overview and Summary Information (AV-1)

Description: The Hydrogen Delivery System Initial Phase architecture supports a Centralized Production and Distribution Model (rationale for Centralized Production below (i.e. reduce infrastructure costs by leveraging large existing production facilities such as refineries and current hydrogen plants). Initial Phase Scenario: Production occurs at a large facility and delivered to a terminal facility for delivery to a fuel station or home.

Purpose: The Hydrogen Delivery System Initial Phase architecture is designed to deliver hydrogen to early adopters of Hydrogen Fuel Cell Vehicles (H2 FCV's). The distribution system uses existing production, vehicle transport, terminal and fuel station infrastructure in order to minimize upfront capital expenditures (thereby reducing risk) yet provides enough capacity to serve this market cost effectively. Thus, this early version of the Hydrogen Delivery System has not been designed to scale to support high adoption levels. Only when the system transitions to the Step-Out Phase, will it be able to scale and support high adoption rates.

Scope: The Hydrogen Delivery System for the Initial Phase includes the transport, storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.

Time Frame: Objective

Mission(s):

Deliver Hydrogen Energy — Develop a feasible architecture and investment strategy for a hydrogen distribution system for anticipated usage between 2015 - 2025.

Appendix B.2: Operational Concept (OV-1)

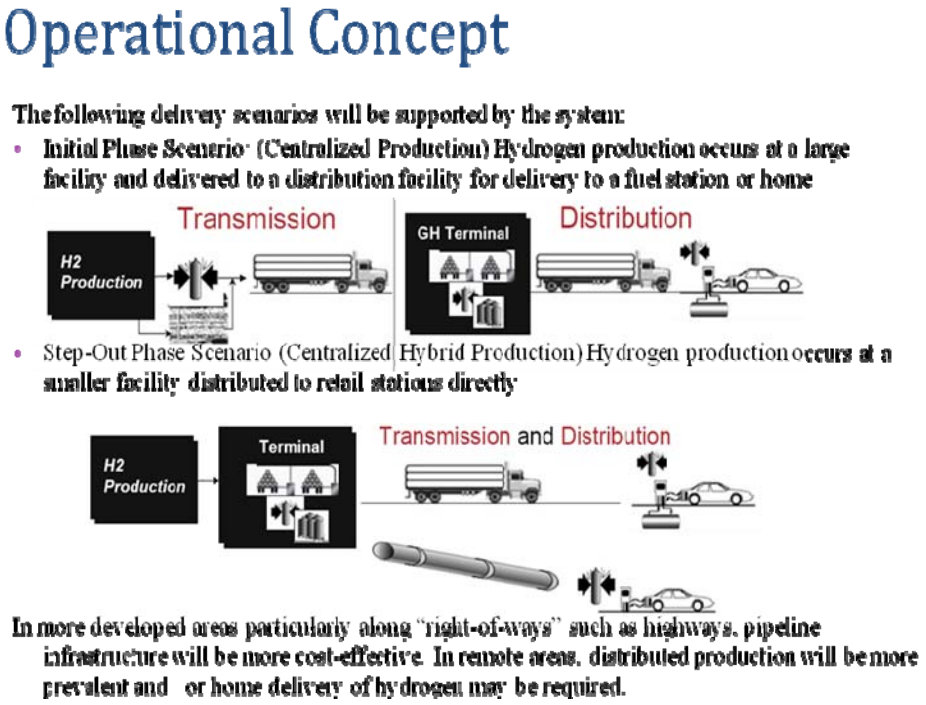

Figure 44. Operational Concept

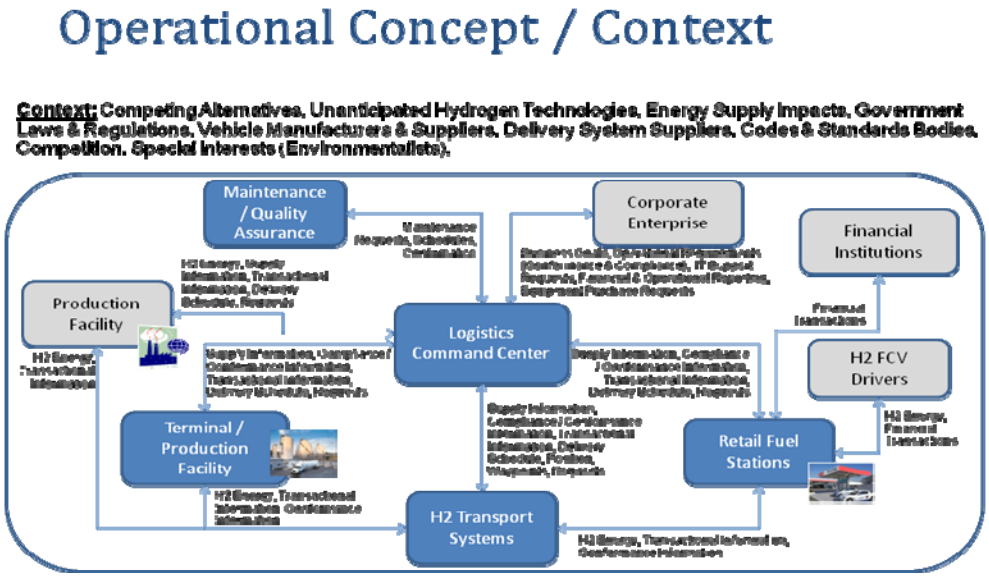

Figure 45. Operational Concept / Context

Appendix B.3: Operational Node Connectivity (OV-2)

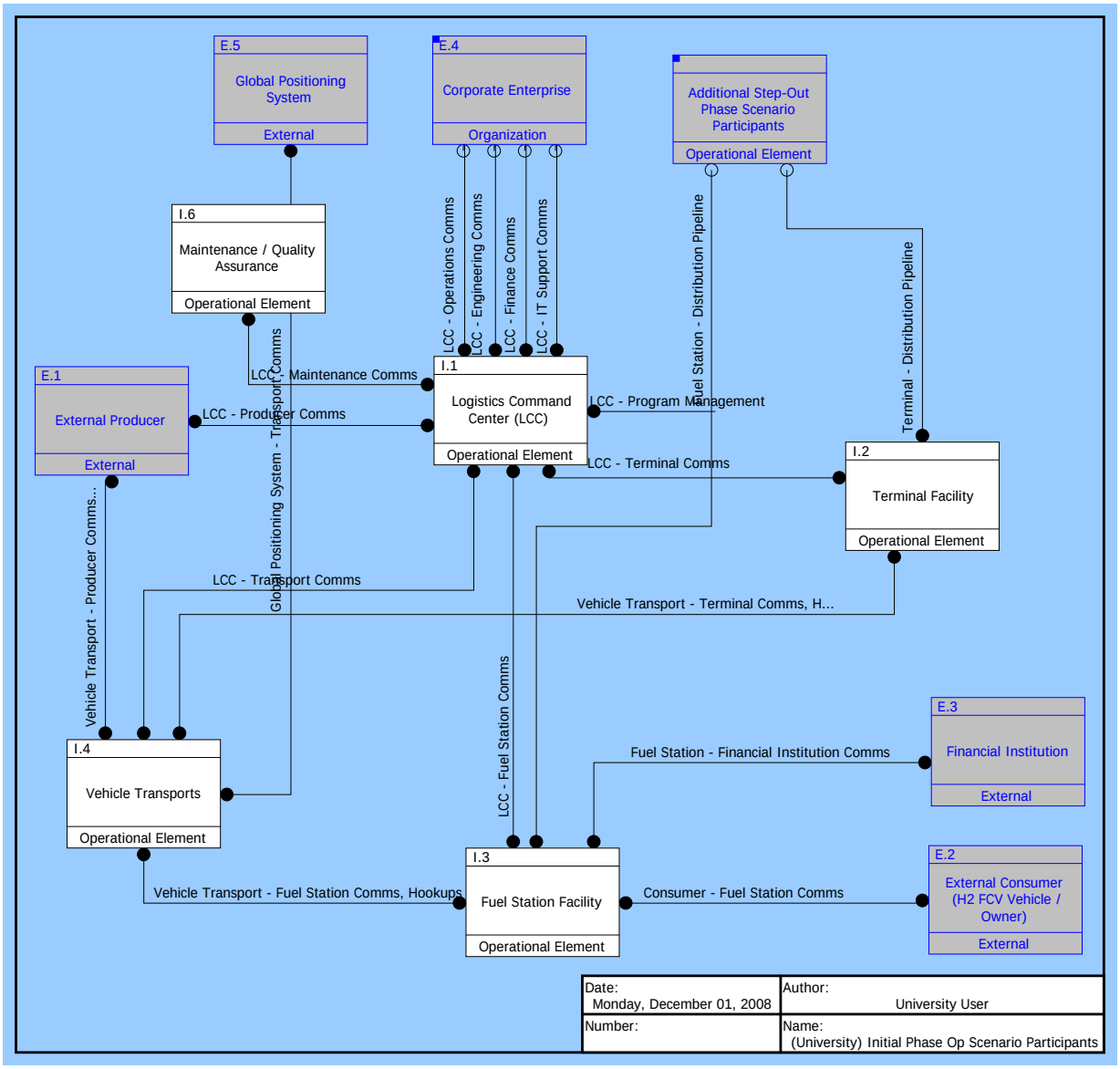

Figure 46. Operational Node Connectivity (OV-2) Diagram

Table 15. Operational Node Connectivity (OV-2) Associated Element Definitions

Element	Definition
Needline	
Consumer - Fuel Station Comms	Supports communications required for retail sale transactions.
Fuel Station - Distribution Pipeline	Supports Distribution of Hydrogen to the Fuel Station from the Terminal.
Fuel Station - Financial	Supports communications required for securing credit and making payments on

Element	Definition
Institution Comms	behalf of the customer.
Global Positioning System - Transport Comms	Supports communications required for Vehicle Position / Location systems.
LCC - Engineering Comms	Supports communications required for system change management.
LCC - Finance Comms	Supports communications required for corporate financial reporting.
LCC - Fuel Station Comms	Supports communications required for the retail sale of hydrogen, supply transactions and operations management of the Fuel Station.
LCC - IT Support Comms	Supports communications required to remediate problems with company-owned Information Technology supporting system operations.
LCC - Maintenance Comms	Supports communications required for maintenance operations.
LCC - Operations Comms	Supports communications required for auditing and reporting to corporate operations.
LCC - Producer Comms	Supports communications required for supply transactions and supply status information between the Delivery Management System and the Producer.
LCC - Program Management	
LCC - Terminal Comms	Supports communications required for LCC management of terminal operations.
LCC - Transport Comms	Supports communications required for delivery management.
Terminal - Distribution Pipeline	Support communications between terminal operations and the operating pipeline distribution system and supports terminal supply of hydrogen to the fuel stations.
Vehicle Transport - Fuel Station Comms, Hookups	Supports supply transactions between vehicle transport and fuel station operations.
Vehicle Transport - Producer Comms, Hookup	Supports supply transactions between transports and the producer.
Vehicle Transport - Terminal Comms, Hookups	Supports supply transactions between transports and terminal operations.
OperationalNode	
E.1 External Producer	The External Producer produces bulk amounts of hydrogen and consists of a production component, large bulk storage with interfaces to the Hydrogen Delivery System's Hydrogen Transport Systems.
E.2 External Consumer (H2 FCV Vehicle / Owner)	The External Consumer buys Hydrogen for their Hydrogen Fuel Cell Vehicles.
E.3 Financial Institution	The Financial Institution provides credit and financing to external customers.
E.5 Global Positioning System	The Global Positioning System is a constellation of orbiting satellites which broadcast signals for navigational purposes.
I.1 Logistics Command Center (LCC)	The LCC facility consists of an operations center staffed with personnel responsible for the overall operation of the Hydrogen Delivery System.
I.2 Terminal Facility	The Terminal Facility consists of an unload compressor, loading dispenser, onsite storage, terminal office facility with operators / maintainers.
I.3 Fuel Station Facility	The Fuel Station consists of on-site storage system or pipeline feeder, dispenser and fuel station office and attendant(s).
I.4 Vehicle Transports	The Vehicle Transport System consists of a vehicle, movable storage, onboard vehicle system and driver. Vehicles will operate out of the terminal facility but will be managed by the LCC.

Element	Definition
I.6 Maintenance / Quality Assurance	Maintenance consists of facilities, operators, vehicles and equipment. The maintenance operational element will operate out of (be organic operational element to) the Terminal Facility and will be responsible for terminal operations and maintenance as well as maintenance of the fuel station equipment. Maintenance operations will be managed from the LCC.
Org Corporate Participants	The corporate financial system is external to the delivery system, but internal to the corporation. It maintains the corporation's books using reporting information generated by the B2B system.
Additional Step-Out Phase Scenario Participants	The Additional Step-Out Phase Scenario Participants includes Pipeline Distribution in addition to Initial Phase Scenario Operational Elements. For the Step-Out Phase, production will be co-located at the Terminal Facilities but still treated as an external system to the Hydrogen Delivery System. The approach was to define a delta architecture comprising of delta operational nodes and system components. So at the very top-level, if a report or specification is extracted from the core database of the Step-Out architecture, that report will include both the Initial Phase architecture and the additional elements in the step out phase.
Initial Phase Op Scenario Participants	Initial Phase Operational Scenario Participants include all operational elements except Pipeline Distribution, which is implemented during the Step-Out Phase.

Appendix B.4: Operational Information Exchange Matrix (OV-3)

Table 16. Operational Information Exchange Matrix (OV-3)

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
Consumer - Fuel Station Comms	Consumer Pressure Selection	Consumer selection of pressure hose required to fuel H2 FCV. Consumer selection of 2 k psi, 5 k psi or 10 k psi dispenser hoses.		External Consumer (H2 FCV Vehicle / Owner) *Purchase Hydrogen Energy*	Fuel Station Facility *Perform Fuel Station Operations*
	Dispenser Deactivation	Deactivation of the dispenser. Consumer deactivates the dispenser by returning the dispenser nozzle to the pump.		External Consumer (H2 FCV Vehicle / Owner) *Purchase Hydrogen Energy*	Fuel Station Facility *Perform Fuel Station Operations*
	Payment Method Selection	Consumer selection of desired payment method. Consumer selects either Cash or Credit Payment Method.		External Consumer (H2 FCV Vehicle / Owner) *Purchase Hydrogen Energy*	Fuel Station Facility *Perform Fuel Station Operations*
Fuel Station - Distribution Pipeline					
Fuel Station - Financial Institution Comms	Consumer Transaction Information	Consumer Transaction Information contains the amount of hydrogen dispensed, the cost per Kg of hydrogen and the total transaction amount. Consumer Transaction Information message is sent once the retail sale transaction is complete.		Fuel Station Facility *Perform Fuel Station Operations*	Financial Institution *Provide Credit*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
Global Positioning System - Transport Comms	GPS Signal	GPS Signal is the signal transmitted by GPS satellites used by the Vehicle Transports to determine position.		Global Positioning System *Provide Location Information*	Vehicle Transports *Monitor and Report Vehicle Transport Information*
LCC - Engineering Comms	Engineering Change Request	Contains details pertaining to system design updates, such as the description of the flaw, how it impacts operations, any steps taken to remediate or address the problem previously and recommended or requested changes that need to be made to the system. Minor design changes are required to address flaws which impact system triggers this request.		Logistics Command Center (LCC) *Manage Supply Operations*	Corporate Enterprise *Develop & Modify Operational System*
LCC - Finance Comms	Financial Reporting	Contains information regarding inventory, assets and delivery and retail transactions.		Logistics Command Center (LCC) *Manage Supply Operations*	Corporate Enterprise *Operate Financial System*
LCC - Fuel Station Comms	Current Fuel Station Supply	Current Fuel Station Supply is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply function.		Fuel Station Facility *Perform Fuel Station Operations*	Logistics Command Center (LCC) *Manage Supply Operations*
	Delivery Request			Fuel Station Facility *Perform Fuel Station Operations*	Logistics Command Center (LCC) *Manage Supply Operations*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
	Delivery Schedule	Delivery Schedule is a set of dates and times that transports are due to pickup and deliver hydrogen.		Logistics Command Center (LCC) *Manage Supply Operations*	Fuel Station Facility *Perform Fuel Station Operations*
	Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.		Fuel Station Facility *Perform Fuel Station Operations*	Logistics Command Center (LCC) *Manage Supply Operations*
	Maintenance Schedule	Maintenance required is used to communicate the repair action and location required and acts as a confirmation to the maintenance request.		Maintenance & Compliance *Perform Maintenance & Compliance Operations*	Logistics Command Center (LCC) *Manage Supply Operations* Fuel Station Facility *Perform Fuel Station Operations*
	Transport Transaction Information	Transport Transaction Information contains information regarding loading and unloading transactions, such as amount, cost per Kg and total value of load. This message is sent at the end of a load or unloads transaction.		Fuel Station Facility *Perform Fuel Station Operations*	Logistics Command Center (LCC) *Manage Supply Operations*
LCC - IT Support Comms	Request IT Support	IT Support Requests are made when company-owned Information Technology asset failure affects the		Logistics Command Center (LCC) *Manage Supply Operations*	Corporate Enterprise *Provide Operational IT Support*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
		overall operation of the system.			
LCC - Maintenance Comms	Maintenance Complete	Maintenance Complete is a message that is a positive acknowledgement to a maintenance request, providing the start / end time of the repair and any downtime, the repair actions, equipment used and parts required, maintenance personnel name and identification number. It also indicates any follow up maintenance or repairs that may be required.		Maintenance & Compliance *Perform Maintenance & Compliance Operations*	Logistics Command Center (LCC) *Manage Supply Operations*
	Maintenance Dispatch	Maintenance Dispatch is a message that captures and describes a problem, remediation actions required (in addition to specialized equipment required - if any), proposed repair times and assigns a priority to the problem. The priority is used by maintenance operations in order to schedule maintenance activities. This schedule is providing to the LCC and relevant system operators to manage around repairs which may cause operational impacts.		Logistics Command Center (LCC) *Manage Supply Operations*	Maintenance & Compliance *Perform Maintenance & Compliance Operations*
	Maintenance	Maintenance required is used		Maintenance &	Logistics Command

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
	Schedule	to communicate the repair action and location required and acts as a confirmation to the maintenance request.		Compliance *Perform Maintenance & Compliance Operations*	Center (LCC) *Manage Supply Operations*
LCC - Operations Comms	New Equipment Request	New Equipment Request is sent when new parts or equipment is required be made (manufacturing) or purchased (procurement) to support maintenance operations.		Logistics Command Center (LCC) *Manage Supply Operations*	Maintenance & Compliance *Perform Maintenance & Compliance Operations*
	Operational Conformance & Compliance Information	Information from internal audits is reported back to corporate operations.		Logistics Command Center (LCC) *Manage Supply Operations*	Corporate Enterprise *Enforce Operational Conformance*
	Request Facilities Maintenance	Facilities Maintenance Requests are made when the condition of company-owned facilities or property affects the operation of the overall system.		Logistics Command Center (LCC) *Manage Supply Operations*	Corporate Enterprise *Provide Facilities & Maintenance Support*
	Required Compliance / Conformance Actions	Actions to remediate non-compliant system operation.		Corporate Enterprise *Enforce Operational Conformance*	Logistics Command Center (LCC) *Manage Supply Operations*
LCC - Producer Comms	Consumer Demand Information	Consumer Demand Information is reported to the producer in order for the producer to meet current hydrogen consumption rates.		Logistics Command Center (LCC) *Manage Supply Operations*	External Producer *Provide Hydrogen Energy Supply*
	Delivery Schedule	Delivery Schedule is a set of dates and times that		Logistics Command Center (LCC)	Logistics Command Center (LCC)

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
		transports are due to pickup and deliver hydrogen.		*Manage Supply Operations*	*Manage Supply Operations*
	Hydrogen Supply Information Request	Request to the producer to provide information regarding available hydrogen supply on-hand (stored) and current operating capacity.		Logistics Command Center (LCC) *Manage Supply Operations*	External Producer *Provide Hydrogen Energy Supply*
	Producer Supply Information	Producer Supply Information indicates the available supply of stored hydrogen at the production site and the rate at which hydrogen is being produced.		External Producer *Provide Hydrogen Energy Supply*	Logistics Command Center (LCC) *Manage Supply Operations*
	Transport Transaction Information	Transport Transaction Information contains information regarding loading and unloading transactions, such as amount, cost per Kg and total value of load. This message is sent at the end of a load or unloads transaction.		External Producer *Provide Hydrogen Energy Supply*	Logistics Command Center (LCC) *Manage Supply Operations*
LCC - Program Management	Report Operational Status / Metrics	Required reporting of operational status and metrics (measured established by program management plan and process).		Logistics Command Center (LCC) *Manage Supply Operations*	External Program Management *Manage Programs*
LCC - Terminal Comms	Current Terminal Supply	Current Terminal Supply is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply		Terminal Facility *Perform Terminal Operations*	Logistics Command Center (LCC) *Manage Supply Operations*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
		function.			
	Delivery Schedule	Delivery Schedule is a set of dates and times that transports are due to pickup and deliver hydrogen.		Logistics Command Center (LCC) *Manage Supply Operations*	Terminal Facility *Perform Terminal Operations*
	Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.		Terminal Facility *Perform Terminal Operations*	Logistics Command Center (LCC) *Manage Supply Operations*
	Maintenance Schedule	Maintenance required is used to communicate the repair action and location required and acts as a confirmation to the maintenance request.		Maintenance & Compliance *Perform Maintenance & Compliance Operations*	Logistics Command Center (LCC) *Manage Supply Operations* Terminal Facility *Perform Terminal Operations*
	Pipeline Pressure Setting	Set Pipeline Pressure sets the pressure on the pipeline controlling the flow of hydrogen through the pipeline distribution system.		Logistics Command Center (LCC) *Manage Supply Operations*	Terminal Facility *Move Hydrogen Energy*
	Transport Transaction Information	Transport Transaction Information contains information regarding loading and unloading transactions, such as amount, cost per Kg and total value of load. These messages are		Terminal Facility *Perform Terminal Operations*	Logistics Command Center (LCC) *Manage Supply Operations*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
		sent at the end of a load or unload transaction.			
LCC - Transport Comms	Delivery Schedule	Delivery Schedule is a set of dates and times that transports are due to pickup and deliver hydrogen.		Logistics Command Center (LCC) *Manage Supply Operations*	Vehicle Transports *Move Empty Transport*
	Location Information	The Location Information of the Vehicle Transport.		Vehicle Transports *Monitor and Report Vehicle Transport Information*	Logistics Command Center (LCC) *Manage Supply Operations*
	Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.		Maintenance & Compliance *Perform Maintenance & Compliance Operations*	Logistics Command Center (LCC) *Manage Supply Operations*
	Maintenance Schedule	Maintenance required is used to communicate the repair action and locations required and act as a confirmation to the maintenance request.		Maintenance & Compliance *Perform Maintenance & Compliance Operations*	Logistics Command Center (LCC) *Manage Supply Operations*
	Transport Dispatch	Trigger is used to dispatch empty transports to pickup hydrogen and make deliveries.		Logistics Command Center (LCC) *Manage Supply Operations*	Vehicle Transports *Store & Transport Hydrogen*
Vehicle Transport - Fuel Station Comms, Hookups	Delivery Conformance Report	The Delivery Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It		Fuel Station Facility *Store & Transport Hydrogen*	Fuel Station Facility *Perform Fuel Station Operations*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
		contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.			
	Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.		Fuel Station Facility *Perform Fuel Station Operations*	Fuel Station Facility *Store & Transport Hydrogen*
	Unload Complete / Metered Amount	Unload Compete signals completion of the unload activity and contains the metered amount unloaded.		Fuel Station Facility *Unload Hydrogen Energy*	Fuel Station Facility *Complete Unload Transaction*
	Unload Invoice / Billing Statement (Issued)	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.		Fuel Station Facility *Store & Transport Hydrogen*	Fuel Station Facility *Perform Fuel Station Operations*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
	Unload Request	Schedule Pickup is scheduled with Production and Terminal Operations.		Fuel Station Facility *Store & Transport Hydrogen*	Fuel Station Facility *Perform Fuel Station Operations*
Vehicle Transport - Producer Comms, Hookup	Fill Tag	The fill tag is attached to the hookup connection / valve on the vehicle transport trailer and is cross-referenced to the Delivery Conformance Report describing the H2 purity and composition of gases.		Vehicle Transports *Complete Load Transaction*	Vehicle Transports *Complete Unload Transaction*
	Load Authorization	Load Authorization is a signal used to activate the load dispenser.		External Producer *Provide Hydrogen Energy Supply*	Vehicle Transports *Store & Transport Hydrogen*
	Load Complete / Metered Amount	Load Compete signals completion of the load activity and contains the metered amount loaded.		Vehicle Transports *Load Transport*	Vehicle Transports *Complete Load Transaction*
	Load Invoice / Billing Statement (Received)	Load Invoice contains the amount of H2 loaded, price paid per Kg of H2 and the total value of H2 loaded.		External Producer *Provide Hydrogen Energy Supply*	Vehicle Transports *Store & Transport Hydrogen*
	Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.		Vehicle Transports *Move Empty Transport*	Vehicle Transports *Load Transport* External Producer *Provide Hydrogen Energy Supply*
	Producer Conformance Report	The Producer Conformance Report is provided by the vehicle transport driver to the terminal or fuel station		External Producer *Provide Hydrogen Energy Supply*	Vehicle Transports *Store & Transport Hydrogen*

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
		operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.			
Vehicle Transport - Terminal Comms, Hookups	Fill Tag	The fill tag is attached to the hookup connection / valve on the vehicle transport trailer and is cross-referenced to the Delivery Conformance Report describing the H2 purity and composition of gases.		Terminal Facility *Complete Load Transaction*	Terminal Facility *Complete Unload Transaction*
	Load Authorization	Load Authorization is a signal used to activate the load dispenser.		Terminal Facility *Perform Terminal Operations*	Terminal Facility *Store & Transport Hydrogen*
	Load Complete / Metered Amount	Load Compete signals completion of the load activity and contains the metered amount loaded.		Terminal Facility *Load Transport*	Terminal Facility *Complete Load Transaction*
	Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.		Vehicle Transports *Move Empty Transport*	Terminal Facility *Load Transport*
	Unload	Unload Authorization is a		Terminal Facility	Terminal Facility

Needline	Operational Information Element			Information Source	Information Destination
Name	**Name**	**Description**	**Attributes**	**Node and Activity**	**Node and Activity**
	Authorization	signal used to activate the unload storage compressor.		*Perform Terminal Operations*	*Store & Transport Hydrogen*
	Unload Complete / Metered Amount	Unload Compete signals completion of the unload activity and contains the metered amount unloaded.		Terminal Facility *Unload Hydrogen Energy*	Terminal Facility *Complete Unload Transaction*
	Unload Invoice / Billing Statement (Issued)	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.		Terminal Facility *Store & Transport Hydrogen*	Terminal Facility *Perform Terminal Operations*
	Unload Request	Schedule Pickup is scheduled with Production and Terminal Operations.		Terminal Facility *Store & Transport Hydrogen*	Terminal Facility *Perform Terminal Operations*

Appendix B.5: Organizational Relationships (OV-4)

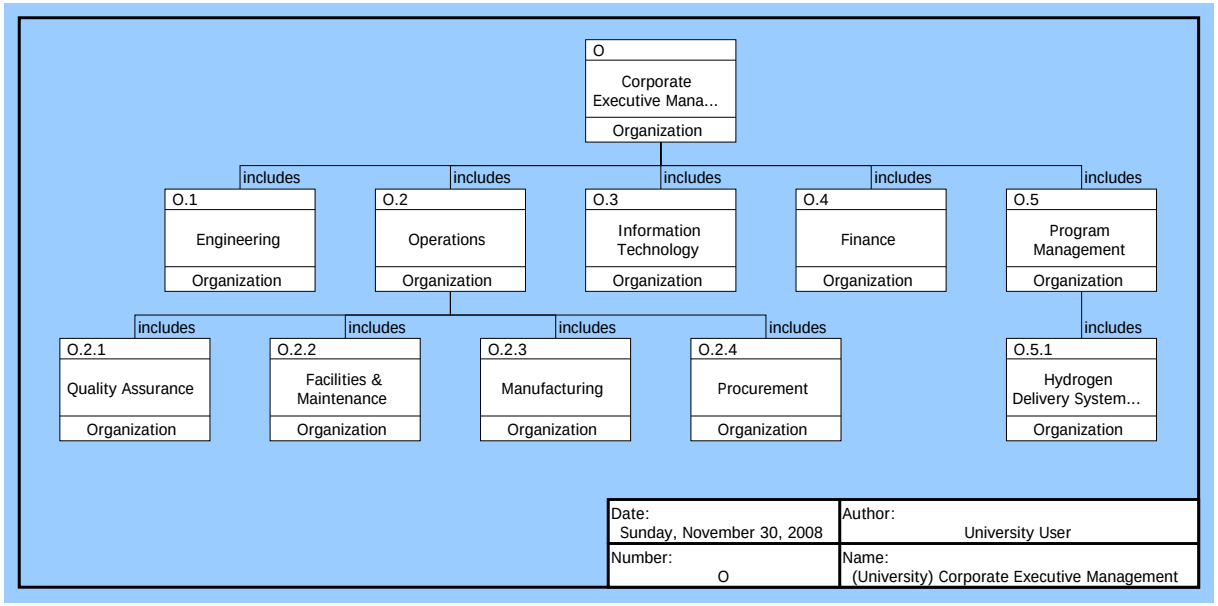

Figure 47. Organizational Relationships (OV-4)

Appendix B.6: Operational Activity Model (OV-5)

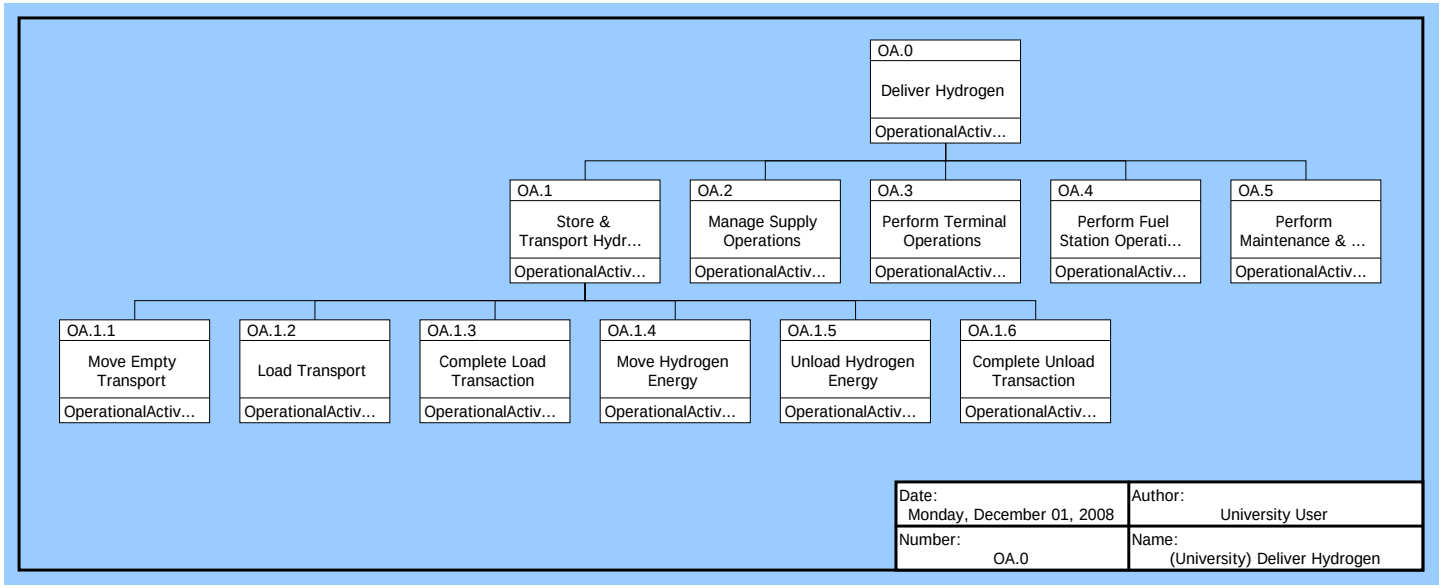

Figure 48. Deliver Hydrogen Hierarchy Diagram

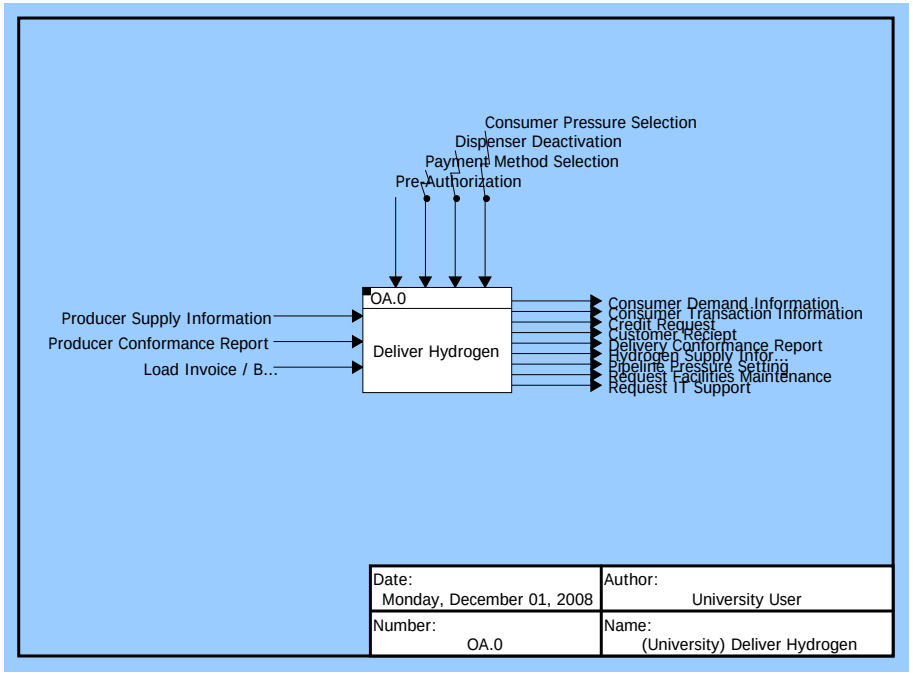

Figure 49. Deliver Hydrogen IDEF0 A-0 Context Diagram

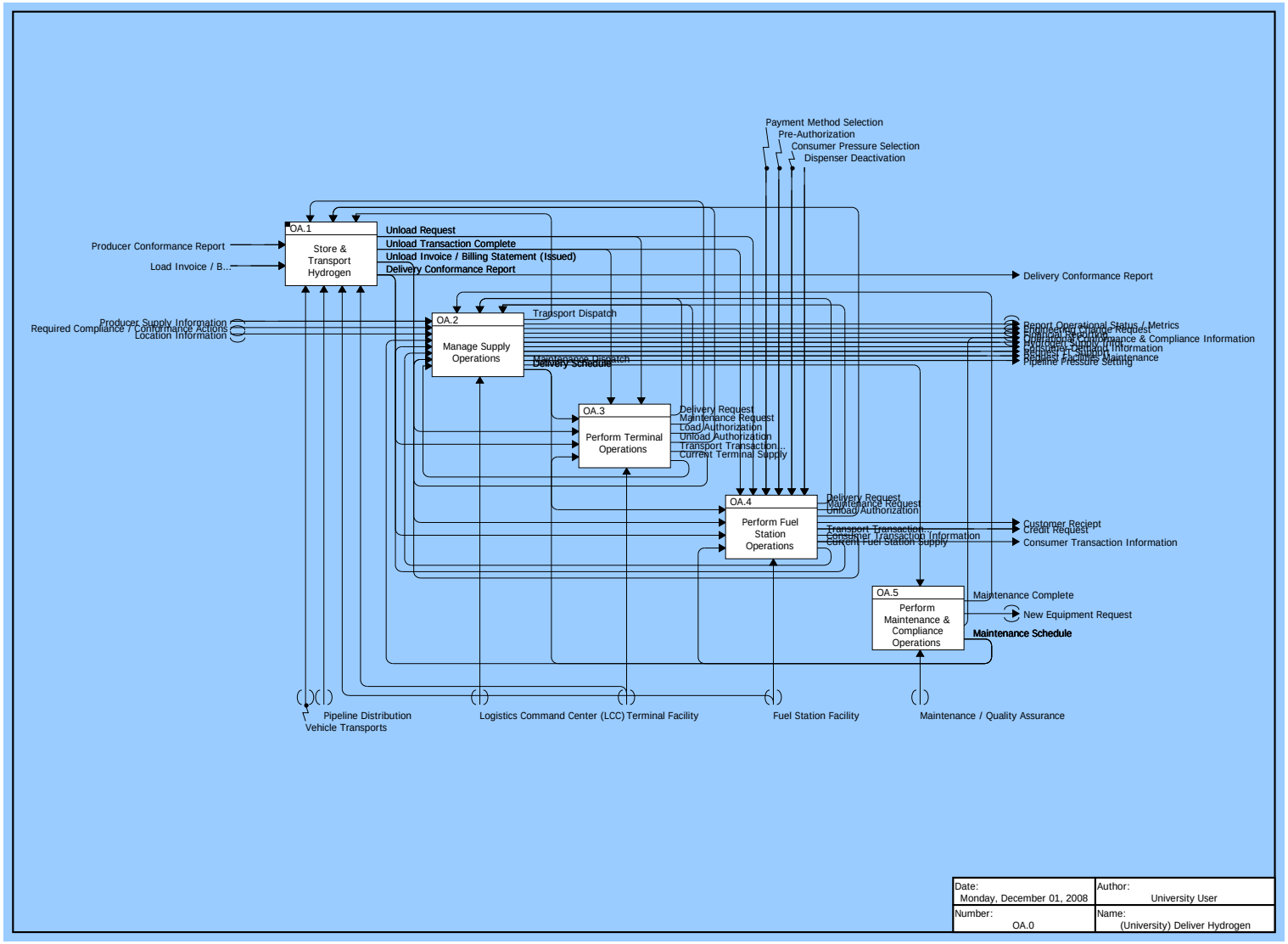

Figure 50. Deliver Hydrogen IDEF0 Diagram

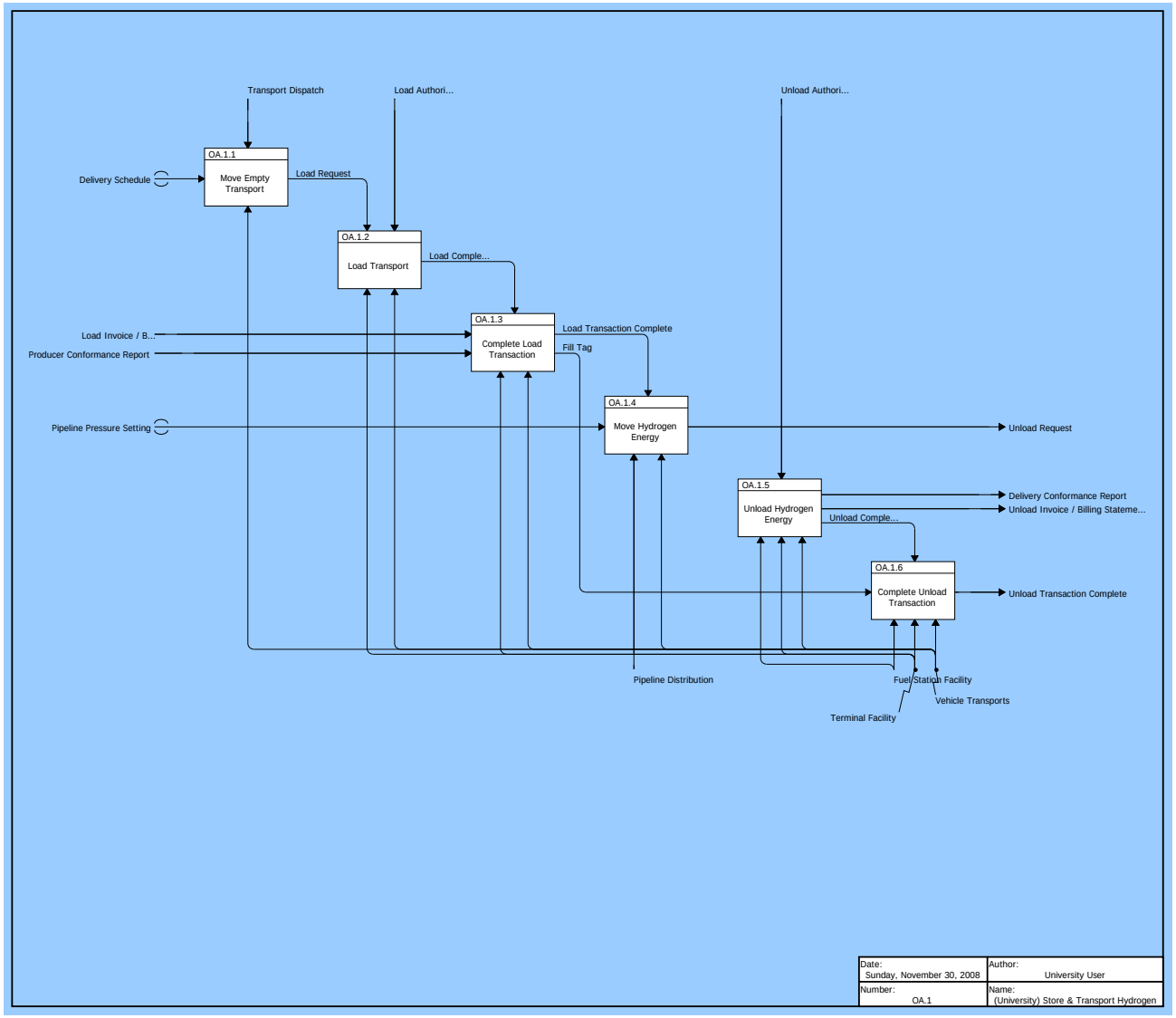

Figure 51. Store & Transport Hydrogen IDEF0 Diagram

Table 17. Operational Activity Model (OV-5) Associated Element Definitions

Element	Definition
	OperationalActivity
OA.0 Deliver Hydrogen	Delivery Hydrogen Operational Activity is responsible for the Delivery of Hydrogen energy from the Producer to the H2 FCV Customer.
OA.1 Store & Transport Hydrogen	The Store & Transport Hydrogen Operational Activity is responsible for moving hydrogen energy through the supply chain.
OA.1.1 Move Empty Transport	The Move Transport Operational Activity is responsible for moving / staging empty transports to producer or terminal facilities to receive a load of hydrogen energy.
OA.1.2 Load Transport	The Load Transport Operational Activity is responsible for activities, interactions and communications required to load hydrogen onto the Vehicle Transports.
OA.1.3 Complete Load Transaction	The Complete Load Transaction Operational Activity is responsible for activities, interactions and communications required to complete the Load Transaction.
OA.1.4 Move Hydrogen Energy	The Move Hydrogen Energy Operational Activity is responsible for moving hydrogen energy to terminal or fuel station facilities.
OA.1.5 Unload Hydrogen Energy	The Unload Transport Operational Activity is responsible for activities, interactions and communications required to unload hydrogen at the terminal or fuel station facilities.
OA.1.6 Complete Unload Transaction	The Complete Unload Transaction Operational Activity is responsible for activities, interactions and communications required to complete the Unload Transaction.
OA.2 Manage Supply Operations	Manage Supply Operations is carried out by the LCC and is responsible for the overall management of all supply, maintenance and compliance activities in addition to supply transactions carried out at the producer, terminal and fuel station facilities.
OA.3 Perform Terminal Operations	Perform Terminal Operations Operation Activity is responsible for the management of operations local to the terminal facility.
OA.4 Perform Fuel Station Operations	Perform Fuel Station Operations Operational Activity is responsible for the operational activities local to the fuel station including supply transactions, hydrogen sales and low-level maintenance of the facilities.
OA.5 Perform Maintenance & Compliance Operations	Perform Maintenance & Compliance Operations is responsible for all maintenance and compliance activities that occur across the system.
	OperationalInformation
Consumer Demand Information	Consumer Demand Information is reported to the producer in order for the producer to meet current hydrogen consumption rates.
Consumer Pressure Selection	Consumer selection of pressure hose required to fuel H2 FCV. Consumer selection of 2 k psi, 5 k psi or 10 k psi dispenser hoses.
Consumer Transaction Information	Consumer Transaction Information contains the amount of hydrogen dispensed, the cost per Kg of hydrogen and the total transaction amount. Consumer Transaction Information message is sent once the retail sale transaction is complete.
Credit Request	Request made by the consumer for credit pre-authorization required prior to dispenser activation.
Current Fuel Station Supply	Current Fuel Station Supply is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply function.
Current Terminal Supply	Current Terminal Supply is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply function.
Customer Receipt	Customer Receipt contains completed transaction information - amount of H2, price per Kg

Element	Definition
	and total amount either paid in cash or charged to credit.
Delivery Conformance Report	The Delivery Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.
Delivery Request	
Delivery Schedule	Delivery Schedule is a set of dates and times that transports are due to pickup and deliver hydrogen.
Dispenser Deactivation	Deactivation of the dispenser. Consumer deactivates the dispenser by returning the dispenser nozzle to the pump.
Engineering Change Request	Contains details pertaining to system design updates, such as the description of the flaw, how it impacts operations, any steps taken to remediate or address the problem previously and recommended or requested changes that need to be made to the system. Minor design changes are required to address flaws which impact system triggers this request.
Fill Tag	The fill tag is attached to the hookup connection / valve on the vehicle transport trailer and is cross-referenced to the Delivery Conformance Report describing the H2 purity and composition of gases.
Financial Reporting	Contains information regarding inventory, assets and delivery and retail transactions.
Hydrogen Supply Information Request	Request to the producer to provide information regarding available hydrogen supply on-hand (stored) and current operating capacity.
Load Authorization	Load Authorization is a signal used to activate the load dispenser.
Load Complete / Metered Amount	Load Compete signals completion of the load activity and contains the metered amount loaded.
Load Invoice / Billing Statement (Received)	Load Invoice contains the amount of H2 loaded, price paid per Kg of H2 and the total value of H2 loaded.
Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.
Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.
Location Information	The Location Information of the Vehicle Transport.
Maintenance Complete	Maintenance Complete is a message that is a positive acknowledgement to a maintenance request, providing the start / end time of the repair and any downtime, the repair actions, equipment used and parts required, maintenance personnel name and identification number. It also indicates any follow up maintenance or repairs that may be required.
Maintenance Dispatch	Maintenance Dispatch is a message that captures and describes a problem, remediation actions required (in addition to specialized equipment required - if any), proposed repair times and assigns a priority to the problem. The priority is used by maintenance operations in order to schedule maintenance activities. This schedule is providing to the LCC and relevant system operators to manage around repairs which may cause operational impacts.
Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.
Maintenance Schedule	Maintenance required is used to communicate the repair action and location required and acts as a confirmation to the maintenance request.

Element	Definition
New Equipment Request	New Equipment Request is sent when new parts or equipment is required be made (manufacturing) or purchased (procurement) to support maintenance operations.
Operational Conformance & Compliance Information	Information from internal audits is reported back to corporate operations.
Payment Method Selection	Consumer selection of desired payment method. Consumer selects either Cash or Credit Payment Method.
Pipeline Pressure Setting	Set Pipeline Pressure sets the pressure on the pipeline controlling the flow of hydrogen through the pipeline distribution system.
Pre-Authorization	Pre-authorization received from a financial institution (credit transaction) or fuel station operator (cash transaction). Pre-Authorization is sent when cash or credit transaction is approved.
Producer Conformance Report	The Producer Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.
Producer Supply Information	Producer Supply Information indicates the available supply of stored hydrogen at the production site and the rate at which hydrogen is being produced.
Report Operational Status / Metrics	Required reporting of operational status and metrics (measured established by program management plan and process).
Request Facilities Maintenance	Facilities Maintenance Requests are made when the condition of company-owned facilities or property affects the operation of the overall system.
Request IT Support	IT Support Requests are made when company-owned Information Technology asset failure affects the overall operation of the system.
Required Compliance / Conformance Actions	Actions to remediate non-compliant system operation.
Transport Dispatch	Trigger is used to dispatch empty transports to pickup hydrogen and make deliveries.
Transport Transaction Information	Transport Transaction Information contains information regarding loading and unloading transactions, such as amount, cost per Kg and total value of load. These messages are sent at the end of a load or unload transaction.
Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.
Unload Complete / Metered Amount	Unload Compete signals completion of the unload activity and contains the metered amount unloaded.
Unload Invoice / Billing Statement (Issued)	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.
Unload Request	Schedule Pickup is scheduled with Production and Terminal Operations.
Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.

Element	Definition
	OperationalNode
Fuel Station Facility	The Fuel Station consists of on-site storage system or pipeline feeder, dispenser and fuel station office and attendant(s).
Logistics Command Center (LCC)	The LCC facility consists of an operations center staffed with personnel responsible for the overall operation of the Hydrogen Delivery System.
Maintenance / Quality Assurance	Maintenance consists of facilities, operators, vehicles and equipment. The maintenance operational element will operate out of (be organic operational element to) the Terminal Facility and will be responsible for terminal operations and maintenance as well as maintenance of the fuel station equipment. Maintenance operations will be managed from the LCC.
Pipeline Distribution	The Pipeline Distribution System consists of pipeline material, pumps and interfaces to terminal and fuel station dispenser.
Terminal Facility	The Terminal Facility consists of an unload compressor, loading dispenser, onsite storage, terminal office facility with operators / maintainers.
Vehicle Transports	The Vehicle Transport System consists of a vehicle, movable storage, onboard vehicle system and driver. Vehicles will operate out of the terminal facility but will be managed by the LCC.

Appendix B.7: Operational Activity Sequence Model (OV-6)

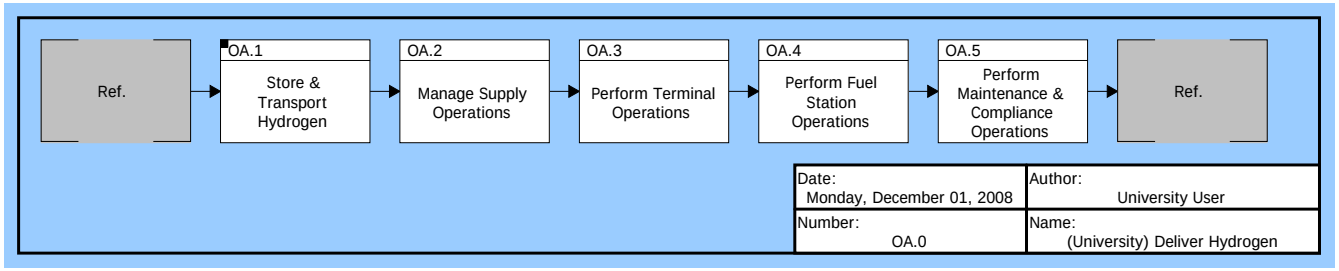

Figure 52. Deliver Hydrogen FFBD

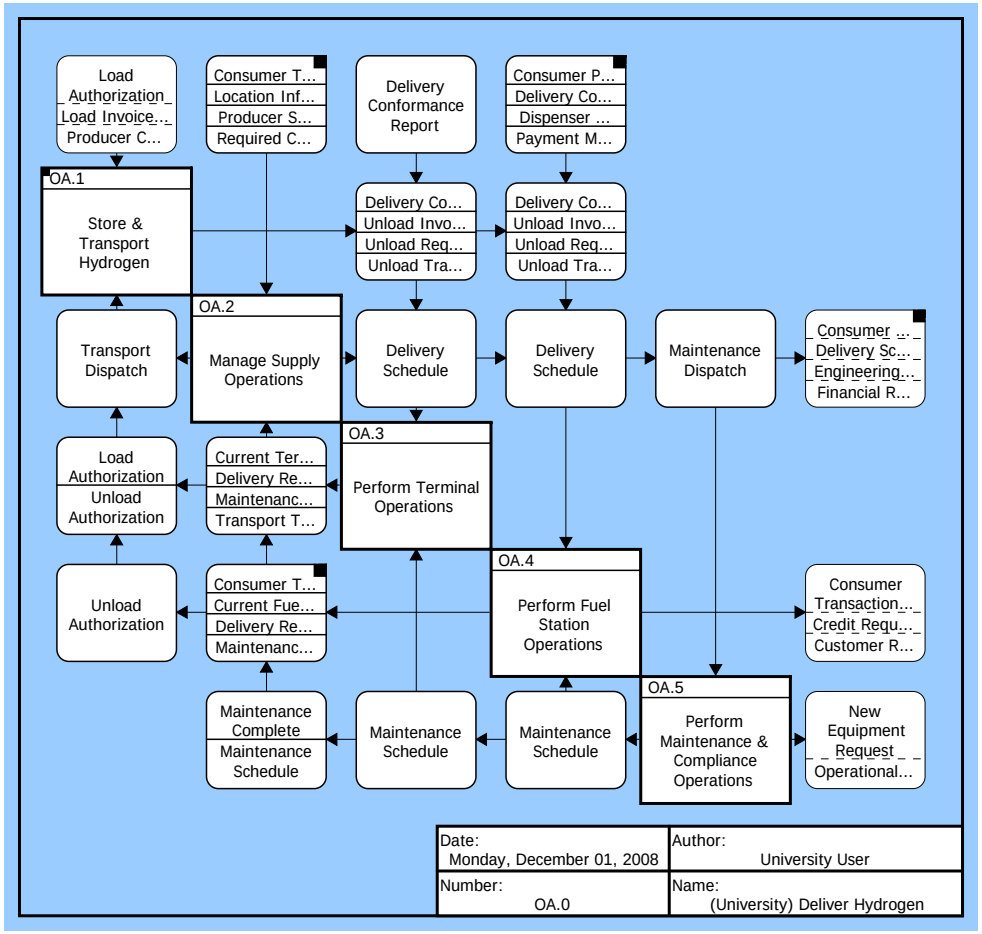

Figure 53. Deliver Hydrogen N2 Diagram

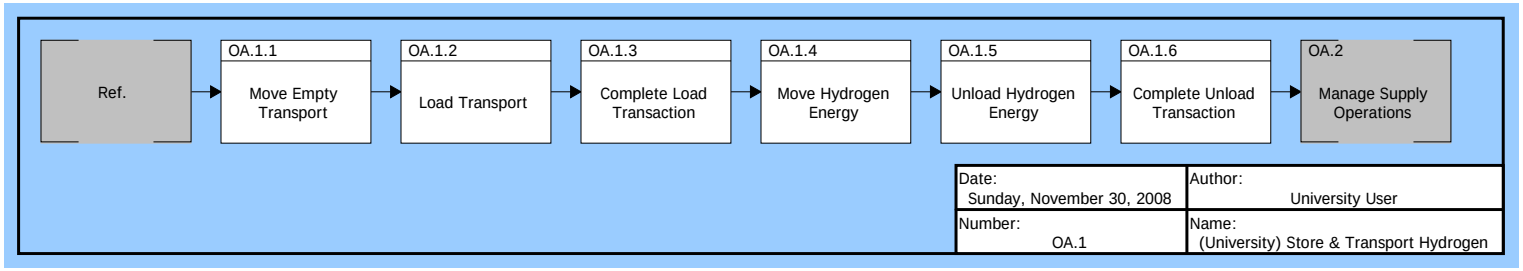

Figure 54. Store & Transport Hydrogen FFBD

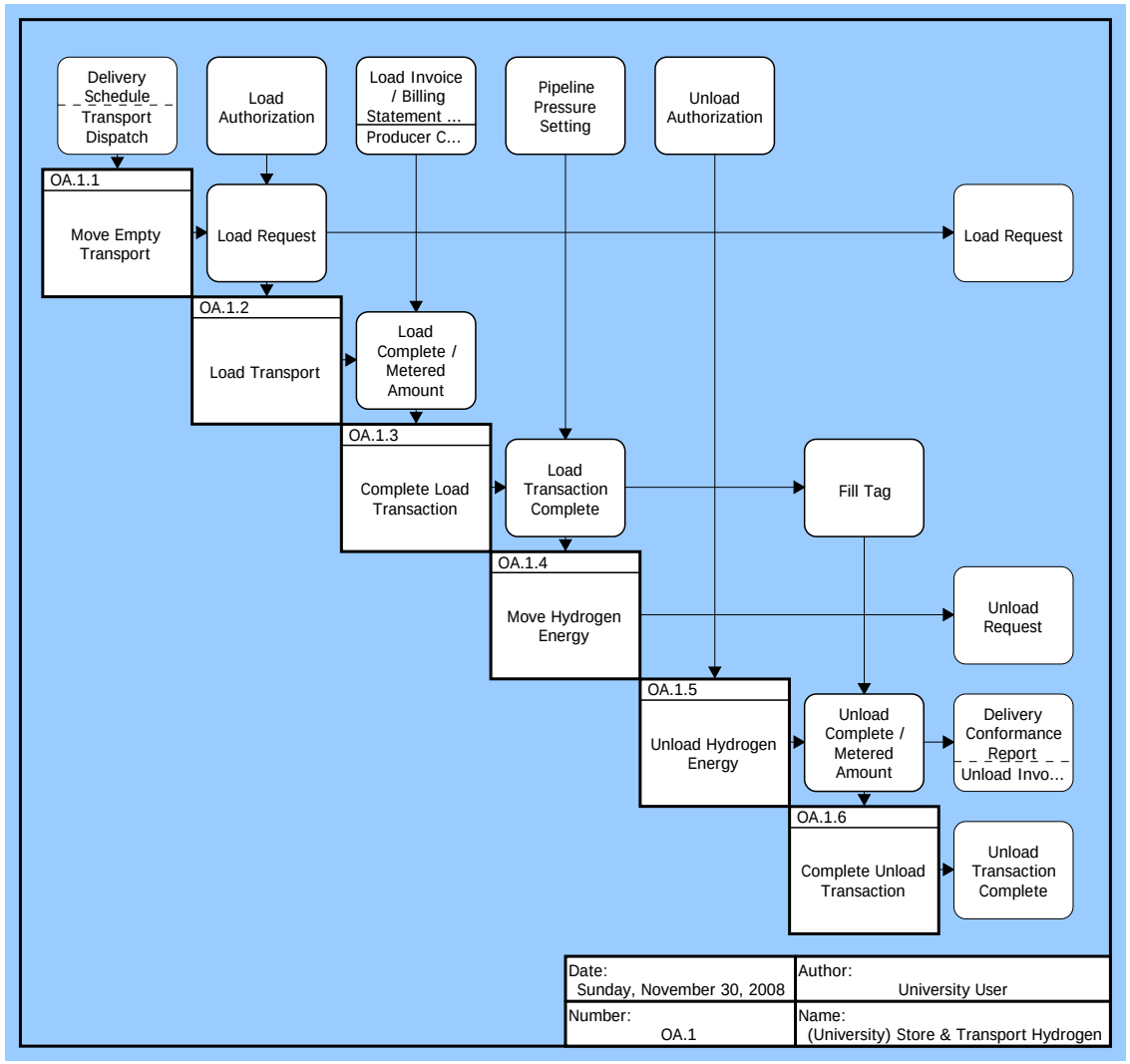

Figure 55. Store & Transport Hydrogen N2 Diagram

Table 18. Operational Activity Sequence Model (OV-6) Associated Element Definitions

Element	Definition
Exit	
Load Authorization Rejected	
Unload Request (Hydrogen Delivery) Rejected	
OperationalActivity	
OA.0 Deliver Hydrogen	Delivery Hydrogen Operational Activity is responsible for the Delivery of Hydrogen energy from the Producer to the H2 FCV Customer.
OA.1 Store & Transport Hydrogen	The Store & Transport Hydrogen Operational Activity is responsible for moving hydrogen energy through the supply chain.
OA.1.1 Move Empty Transport	The Move Transport Operational Activity is responsible for moving / staging empty transports to producer or terminal facilities to receive a load of hydrogen energy.
OA.1.2 Load Transport	The Load Transport Operational Activity is responsible for activities, interactions and communications required to load hydrogen onto the Vehicle Transports.
OA.1.3 Complete Load Transaction	The Complete Load Transaction Operational Activity is responsible for activities, interactions and communications required to complete the Load Transaction.
OA.1.4 Move Hydrogen Energy	The Move Hydrogen Energy Operational Activity is responsible for moving hydrogen energy to terminal or fuel station facilities.
OA.1.5 Unload Hydrogen Energy	The Unload Transport Operational Activity is responsible for activities, interactions and communications required to unload hydrogen at the terminal or fuel station facilities.
OA.1.6 Complete Unload Transaction	The Complete Unload Transaction Operational Activity is responsible for activities, interactions and communications required to complete the Unload Transaction.
OA.2 Manage Supply Operations	Manage Supply Operations is carried out by the LCC and is responsible for the overall management of all supply, maintenance and compliance activities in addition to supply transactions carried out at the producer, terminal and fuel station facilities.
OA.3 Perform Terminal Operations	Perform Terminal Operations Operation Activity is responsible for the management of operations local to the terminal facility.
OA.4 Perform Fuel Station Operations	Perform Fuel Station Operations Operational Activity is responsible for the operational activities local to the fuel station including supply transactions, hydrogen sales and low-level maintenance of the facilities.
OA.5 Perform Maintenance & Compliance Operations	Perform Maintenance & Compliance Operations is responsible for all maintenance and compliance activities that occur across the system.
OperationalInformation	
Consumer Demand Information	Consumer Demand Information is reported to the producer in order for the producer to meet current hydrogen consumption rates.
Consumer Pressure Selection	Consumer selection of pressure hose required to fuel H2 FCV. Consumer selection of 2 k psi, 5 k psi or 10 k psi dispenser hoses.
Consumer Transaction Information	Consumer Transaction Information contains the amount of hydrogen dispensed, the cost per Kg of hydrogen and the total transaction amount. Consumer Transaction Information message is sent once the retail sale transaction is complete.
Credit Request	Request made by the consumer for credit pre-authorization required prior to dispenser activation.
Current Fuel Station Supply	Current Fuel Station Supply is calculated using a tank pressure sensor reading and the size of

Element	Definition
	the tank and is report to the manage supply function.
Current Terminal Supply	Current Terminal Supply is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply function.
Customer Receipt	Customer Receipt contains completed transaction information - amount of H2, price per Kg and total amount either paid in cash or charged to credit.
Delivery Conformance Report	The Delivery Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.
Delivery Request	
Delivery Schedule	Delivery Schedule is a set of dates and times that transports are due to pickup and deliver hydrogen.
Dispenser Deactivation	Deactivation of the dispenser. Consumer deactivates the dispenser by returning the dispenser nozzle to the pump.
Engineering Change Request	Contains details pertaining to system design updates, such as the description of the flaw, how it impacts operations, any steps taken to remediate or address the problem previously and recommended or requested changes that need to be made to the system. Minor design changes are required to address flaws which impact system triggers this request.
Fill Tag	The fill tag is attached to the hookup connection / valve on the vehicle transport trailer and is cross-referenced to the Delivery Conformance Report describing the H2 purity and composition of gases.
Financial Reporting	Contains information regarding inventory, assets and delivery and retail transactions.
Hydrogen Supply Information Request	Request to the producer to provide information regarding available hydrogen supply on-hand (stored) and current operating capacity.
Load Authorization	Load Authorization is a signal used to activate the load dispenser.
Load Complete / Metered Amount	Load Compete signals completion of the load activity and contains the metered amount loaded.
Load Invoice / Billing Statement (Received)	Load Invoice contains the amount of H2 loaded, price paid per Kg of H2 and the total value of H2 loaded.
Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.
Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.
Location Information	The Location Information of the Vehicle Transport.
Maintenance Complete	Maintenance Complete is a message that is a positive acknowledgement to a maintenance request, providing the start / end time of the repair and any downtime, the repair actions, equipment used and parts required, maintenance personnel name and identification number. It also indicates any follow up maintenance or repairs that may be required.
Maintenance Dispatch	Maintenance Dispatch is a message that captures and describes a problem, remediation actions required (in addition to specialized equipment required - if any), proposed repair times and assigns a priority to the problem. The priority is used by maintenance operations in order to schedule maintenance activities. This schedule is providing to the LCC and relevant system operators to manage around repairs which may cause operational impacts.
Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to

Element	Definition
	the LCC.
Maintenance Schedule	Maintenance required is used to communicate the repair action and location required and acts as a confirmation to the maintenance request.
New Equipment Request	New Equipment Request is sent when new parts or equipment is required be made (manufacturing) or purchased (procurement) to support maintenance operations.
Operational Conformance & Compliance Information	Information from internal audits is reported back to corporate operations.
Payment Method Selection	Consumer selection of desired payment method. Consumer selects either Cash or Credit Payment Method.
Pipeline Pressure Setting	Set Pipeline Pressure sets the pressure on the pipeline controlling the flow of hydrogen through the pipeline distribution system.
Pre-Authorization	Pre-authorization received from a financial institution (credit transaction) or fuel station operator (cash transaction). Pre-Authorization is sent when cash or credit transaction is approved.
Producer Conformance Report	The Producer Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.
Producer Supply Information	Producer Supply Information indicates the available supply of stored hydrogen at the production site and the rate at which hydrogen is being produced.
Report Operational Status / Metrics	Required reporting of operational status and metrics (measured established by program management plan and process).
Request Facilities Maintenance	Facilities Maintenance Requests are made when the condition of company-owned facilities or property affects the operation of the overall system.
Request IT Support	IT Support Requests are made when company-owned Information Technology asset failure affects the overall operation of the system.
Required Compliance / Conformance Actions	Actions to remediate non-compliant system operation.
Transport Dispatch	Trigger is used to dispatch empty transports to pickup hydrogen and make deliveries.
Transport Transaction Information	Transport Transaction Information contains information regarding loading and unloading transactions, such as amount, cost per Kg and total value of load. This message is sent at the end of a load or unloads transaction.
Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.
Unload Complete / Metered Amount	Unload Compete signals completion of the unload activity and contains the metered amount unloaded.
Unload Invoice / Billing Statement (Issued)	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.
Unload Request	Schedule Pickup is scheduled with Production and Terminal Operations.
Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.

Appendix B.8: Logical Data Model (OV-7)

Table 19. Logical Data Model (OV-7)

Operational Information	Description	Attributes	Hierarchical Reference
Inf.1 Transport Dispatch	Trigger is used to dispatch empty transports to pickup hydrogen and make deliveries.		
Inf.2 Transport Transaction Information	Transport Transaction Information contains information regarding loading and unloading transactions, such as amount, cost per Kg and total value of load. These messages are sent at the end of a load or unload transaction.		
Inf.3 Load Invoice / Billing Statement (Received)	Load Invoice contains the amount of H2 loaded, price paid per Kg of H2 and the total value of H2 loaded.		
Inf.4 Delivery Conformance Report	The Delivery Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.		
Inf.5 Delivery Schedule	Delivery Schedule is a set of dates and times that transports are due to pickup and deliver hydrogen.		
Inf.6 Fill Tag	The fill tag is attached to the hookup connection / valve on the vehicle transport trailer and is cross-referenced to the Delivery Conformance Report describing the H2 purity and composition of gases.		
Inf.7 Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.		
Inf.8 Load Complete / Metered Amount	Load Compete signals completion of the load activity and contains the metered amount loaded.		
Inf.9 Unload Invoice / Billing Statement (Issued)	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the		

Operational Information	Description	Attributes	Hierarchical Reference
	terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.		
Inf.10 Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.		
Inf.11 Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.		
Inf.12 Delivery Request			
Inf.13 Unload Request	Schedule Pickup is scheduled with Production and Terminal Operations.		
Inf.14 Customer Receipt	Customer Receipt contains completed transaction information - amount of H2, price per Kg and total amount either paid in cash or charged to credit.		
Inf.15 Consumer Demand Information	Consumer Demand Information is reported to the producer in order for the producer to meet current hydrogen consumption rates.		
Inf.16 Current Fuel Station Supply	Current Fuel Station Supply is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply function.		
Inf.17 Current Terminal Supply	Current Terminal Supply is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply function.		
Inf.18 Producer Supply Information	Producer Supply Information indicates the available supply of stored hydrogen at the production site and the rate at which hydrogen is being produced.		
Inf.19 Load Authorization	Load Authorization is a signal used to activate the load dispenser.		
Inf.20 Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.		

Operational Information	Description	Attributes	Hierarchical Reference
Inf.21 Unload Complete / Metered Amount	Unload Compete signals completion of the unload activity and contains the metered amount unloaded.		
Inf.22 Hydrogen Supply Information Request	Request to the producer to provide information regarding available hydrogen supply on-hand (stored) and current operating capacity.		
Inf.23 Pipeline Pressure Setting	Set Pipeline Pressure sets the pressure on the pipeline controlling the flow of hydrogen through the pipeline distribution system.		
Inf.24 Payment Method Selection	Consumer selection of desired payment method. Consumer selects either Cash or Credit Payment Method.		
Inf.25 Credit Request	Request made by the consumer for credit pre-authorization required prior to dispenser activation.		
Inf.26 Pre-Authorization	Pre-authorization received from a financial institution (credit transaction) or fuel station operator (cash transaction). Pre-Authorization is sent when cash or credit transaction is approved.		
Inf.27 Consumer Transaction Information	Consumer Transaction Information contains the amount of hydrogen dispensed, the cost per Kg of hydrogen and the total transaction amount. Consumer Transaction Information message is sent once the retail sale transaction is complete.		
Inf.28 Consumer Pressure Selection	Consumer selection of pressure hose required to fuel H2 FCV. Consumer selection of 2 k psi, 5 k psi or 10 k psi dispenser hoses.		
Inf.29 Producer Conformance Report	The Producer Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.		
Inf.30 Request Facilities Maintenance	Facilities Maintenance Requests are made when the condition of company-owned facilities or property affects the operation of the overall system.		
Inf.31 Request IT Support	IT Support Requests are made when company-owned Information Technology asset failure affects the overall		

Operational Information	Description	Attributes	Hierarchical Reference
	operation of the system.		
Inf.32 Engineering Change Request	Contains details pertaining to system design updates, such as the description of the flaw, how it impacts operations, any steps taken to remediate or address the problem previously and recommended or requested changes that need to be made to the system. Minor design changes are required to address flaws which impact system triggers this request.		
Inf.33 New Equipment Request	New Equipment Request is sent when new parts or equipment is required be made (manufacturing) or purchased (procurement) to support maintenance operations.		
Inf.34 Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.		
Inf.35 Maintenance Schedule	Maintenance required is used to communicate the repair action and location required and acts as a confirmation to the maintenance request.		
Inf.36 Maintenance Dispatch	Maintenance Dispatch is a message that captures and describes a problem, remediation actions required (in addition to specialized equipment required - if any), proposed repair times and assigns a priority to the problem. The priority is used by maintenance operations in order to schedule maintenance activities. This schedule is providing to the LCC and relevant system operators to manage around repairs which may cause operational impacts.		
Inf.37 Maintenance Complete	Maintenance Complete is a message that is a positive acknowledgement to a maintenance request, providing the start / end time of the repair and any downtime, the repair actions, equipment used and parts required, maintenance personnel name and identification number. It also indicates any follow up maintenance or repairs that may be required.		
Inf.38 Operational Conformance & Compliance Information	Information from internal audits is reported back to corporate operations.		
Inf.39 Required Compliance / Conformance Actions	Actions to remediate non-compliant system operation.		
Inf.40 Dispenser Deactivation	Deactivation of the dispenser. Consumer deactivates the		

Operational Information	Description	Attributes	Hierarchical Reference
	dispenser by returning the dispenser nozzle to the pump.		
Inf.41 Report Operational Status / Metrics	Required reporting of operational status and metrics (measured established by program management plan and process).		
Inf.43 Financial Reporting	Contains information regarding inventory, assets and delivery and retail transactions.		
Inf.44 Location Information	The Location Information of the Vehicle Transport.		

Appendix B.9: Systems/ Services Interface Diagram (SV-1)

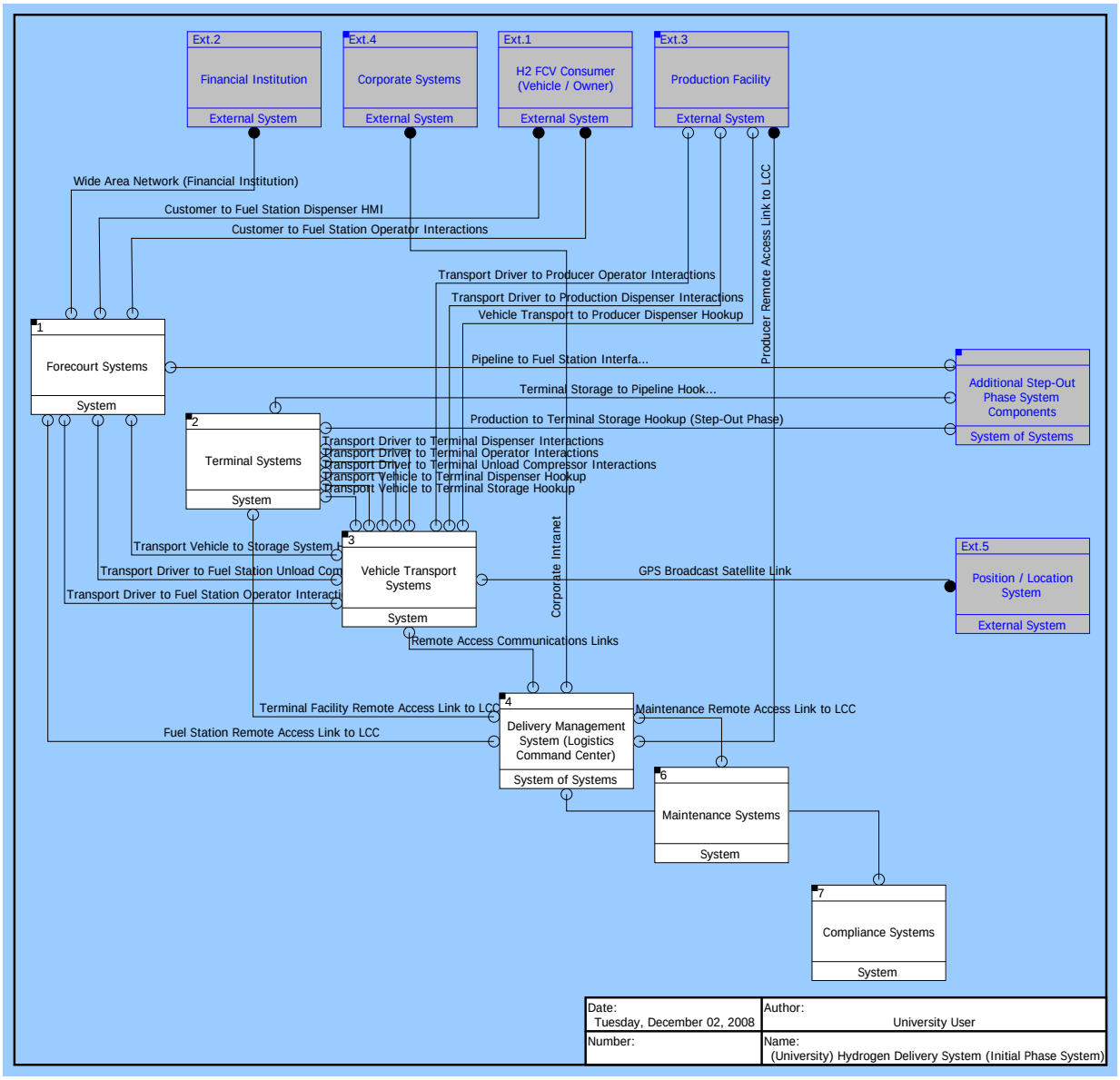

Figure 56. Systems / Services Interface Diagram (SV-1)

Table 20. Systems / Services Interface Diagram (SV-1) Associated Element Definitions

Element	Definition
Component	
1 Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
2 Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
3 Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.
4 Delivery Management System (Logistics Command Center)	The Delivery Management System is responsible for automating the management of the hydrogen supply, conformance to hydrogen fuel standards and maintenance of the Hydrogen Delivery System.
6 Maintenance Systems	Compliance systems are used by systems maintainers in order to measure the system operational performance. This information is used by the maintainer to make repairs to the system or remediate non-conformation to operational requirements.
7 Compliance Systems	
Ext.1 H2 FCV Consumer (Vehicle / Owner)	End consumer for H2 energy product being provided by the Hydrogen Delivery System.
Ext.2 Financial Institution	The main role of the external financial institution in this architecture is to support transactions between the end consumers for hydrogen and the corporation.
Ext.3 Production Facility	The Production Facility is the source of Hydrogen Energy for the Hydrogen Delivery System. Located at the Production Facility are a Storage System and Load Dispenser capable of loading Vehicle Transports with Compressed Hydrogen Gas.
Ext.4 Corporate Systems	Corporate Systems is a collection of Information Systems which are a part of the corporate enterprise which support the functional organization.
Ext.5 Position / Location System	A constellation of satellites called the Global Positioning System.
Additional Step-Out Phase System Components	The Hydrogen Delivery System Step-Out Phase transitions external production to the terminal facilities in order to flatten the distribution network, effectively lowering hydrogen delivery costs by bringing production closer to the retail fuel stations. It also potentially adds pipeline distribution in areas where there are right-of-ways (such as highways) and where there are not urban pressure restrictions. The Hydrogen Delivery System Step-Out Phase will be implemented as the H2 FCV market develops with the key decision point to go forward occurring in 2018, as H2 FCV market adoption starts to ramp up. The Hydrogen Delivery System for the Step-Out phase will be a more scalable and efficient architecture versus the Initial Phase due to the flattening of the distribution network and addition of pipeline distribution, but will require significant capital expenditures to co-locate hydrogen production at the terminals and to build out the pipeline infrastructure. The Hydrogen Delivery System for the Step-Out Phase includes the transport (vehicular and pipeline), storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery

Element	Definition
	operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Hydrogen Delivery System (Initial Phase System)	The Hydrogen Delivery System Initial Phase architecture supports a Centralized Production distribution model. Initial Phase Scenario: Production occurs at a large facility and delivered to a terminal facility for delivery to a fuel station. The Hydrogen Delivery System for the Initial Phase includes the transport, storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Link	
CMS to LCC Link	
Corporate Intranet	Provides the LCC connectivity back to the corporate enterprise and Information Technology infrastructure.
Customer to Fuel Station Dispenser HMI	Provides the customer a Human-Machine Interface to the Dispenser in order to support dispensing of hydrogen and sales transactions.
Customer to Fuel Station Operator Interactions	Supports verbal communications that may occur between the Customer and the Fuel Station Operator.
Fuel Station Remote Access Link to LCC	The Fuel Station remote access link provides connectivity to the Wide Area Network connecting operational node elements.
GPS Broadcast Satellite Link	Provides the positioning signal required by the Position / Location System on the Vehicle Transport to determine and report a location.
Maintenance Remote Access Link to LCC	
Pipeline to Fuel Station Interface (Step-Out Phase)	Provides a physical interface between the fuel station and the Pipeline Distribution System. (Step-Out Phase)
Producer Remote Access Link to LCC	Provides a trusted link between the producer and the LCC to support hydrogen demand / supply reporting and load transaction information.
Production to Terminal Storage Hookup (Step-Out Phase)	Connects the Hydrogen Production System, operating at the Terminal, to the Terminal Storage System. (Step-Out Phase)
Remote Access Communications Links	Provides communications links back to the LCC.
Terminal Facility Remote Access Link to LCC	Provides Terminal Facility remote access to the LCC.
Terminal Storage to Pipeline Hookup (Step-Out Phase)	Provides a physical interface between the Terminal Storage System and the Pipeline Distribution System. (Step-Out Phase)
Transport Driver to Fuel Station Operator Interactions	Transport Driver to Fuel Station Link represents the Human-to Human voice communications between the Transport Driver and the Fuel Station Operator.
Transport Driver to Fuel Station Unload Compressor Interactions	Provides an interface between the Vehicle Transport Operator and the Fuel Station Unload Compressor.
Transport Driver to Producer Operator Interactions	Transport Driver to Producer Link represents the Human-to-Human communications between the Transport Driver and the Producer Operator.

Element	Definition
Transport Driver to Production Dispenser Interactions	Provides the Vehicle Transport Driver with an HMI to the Production Load Dispenser.
Transport Driver to Terminal Dispenser Interactions	Provides the Vehicle Transport Driver with an HMI to the Terminal Load Dispenser.
Transport Driver to Terminal Operator Interactions	Supports verbal communications between the Vehicle Transport Operator and the Terminal Operator.
Transport Driver to Terminal Unload Compressor Interactions	Provides the Vehicle Transport Driver with an HMI to the Terminal Unload Compressor.
Transport Vehicle to Storage System Hookup	Provides a physical interface between the Vehicle Transport Storage and the Fuel Station Unload Compressor.
Transport Vehicle to Terminal Dispenser Hookup	Provides the Vehicle Transport Driver with an HMI to the Terminal Load Dispenser.
Transport Vehicle to Terminal Storage Hookup	Provides the Vehicle Transport with a physical interface to the Terminal Storage System.
Vehicle Transport to Producer Dispenser Hookup	Provides a physical interface between the Vehicle Transport Storage and the Production Load Dispenser
Wide Area Network (Financial Institution)	Provides a Wide Area Network connection from the Fuel Station LAN to the Financial Institution.

Appendix B.10: System / Services Communications Diagram (SV-2)

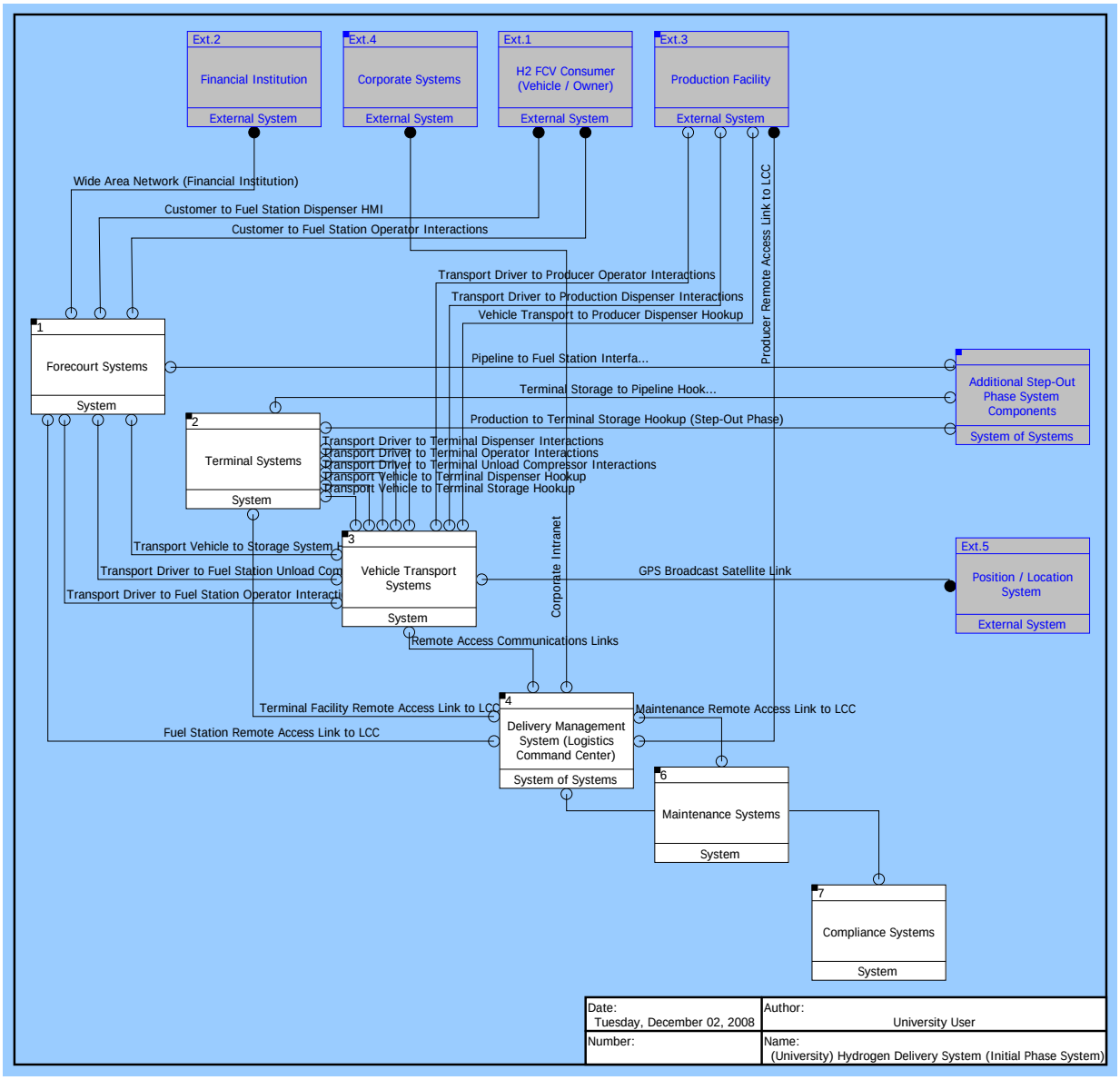

Figure 57. Systems / Services Communications Diagram (SV-2)

Table 21. Systems / Services Communications Diagram (SV-2) Associated Element Definitions

Element	Definition
Component	
1 Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
2 Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
3 Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.
4 Delivery Management System (Logistics Command Center)	The Delivery Management System is responsible for automating the management of the hydrogen supply, conformance to hydrogen fuel standards and maintenance of the Hydrogen Delivery System.
6 Maintenance Systems	Compliance systems are used by systems maintainers in order to measure the system operational performance. This information is used by the maintainer to make repairs to the system or remediate non-conformation to operational requirements.
7 Compliance Systems	
Ext.1 H2 FCV Consumer (Vehicle / Owner)	End consumer for H2 energy product being provided by the Hydrogen Delivery System.
Ext.2 Financial Institution	The main role of the external financial institution in this architecture is to support transactions between the end consumers for hydrogen and the corporation.
Ext.3 Production Facility	The Production Facility is the source of Hydrogen Energy for the Hydrogen Delivery System. Located at the Production Facility are a Storage System and Load Dispenser capable of loading Vehicle Transports with Compressed Hydrogen Gas.
Ext.4 Corporate Systems	Corporate Systems is a collection of Information Systems which are a part of the corporate enterprise which support the functional organization.
Ext.5 Position / Location System	A constellation of satellites called the Global Positioning System.
Additional Step-Out Phase System Components	The Hydrogen Delivery System Step-Out Phase transitions external production to the terminal facilities in order to flatten the distribution network, effectively lowering hydrogen delivery costs by bringing production closer to the retail fuel stations. It also potentially adds pipeline distribution in areas where there are right-of-ways (such as highways) and where there are not urban pressure restrictions. The Hydrogen Delivery System Step-Out Phase will be implemented as the H2 FCV market develops with the key decision point to go forward occurring in 2018, as H2 FCV market adoption starts to ramp up. The Hydrogen Delivery System for the Step-Out phase will be a more scalable and efficient architecture versus the Initial Phase due to the flattening of the distribution network and addition of pipeline distribution, but will require significant capital expenditures to co-locate hydrogen production at the terminals and to build out the pipeline infrastructure. The Hydrogen Delivery System for the Step-Out Phase includes the transport

Element	Definition
	(vehicular and pipeline), storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Hydrogen Delivery System (Initial Phase System)	The Hydrogen Delivery System Initial Phase architecture supports a Centralized Production distribution model. Initial Phase Scenario: Production occurs at a large facility and delivered to a terminal facility for delivery to a fuel station. The Hydrogen Delivery System for the Initial Phase includes the transport, storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Link	
CMS to LCC Link	
Corporate Intranet	Provides the LCC connectivity back to the corporate enterprise and Information Technology infrastructure.
Customer to Fuel Station Dispenser HMI	Provides the customer a Human-Machine Interface to the Dispenser in order to support dispensing of hydrogen and sales transactions.
Customer to Fuel Station Operator Interactions	Supports verbal communications that may occur between the Customer and the Fuel Station Operator.
Fuel Station Remote Access Link to LCC	The Fuel Station remote access link provides connectivity to the Wide Area Network connecting operational node elements.
GPS Broadcast Satellite Link	Provides the positioning signal required by the Position / Location System on the Vehicle Transport to determine and report a location.
Maintenance Remote Access Link to LCC	
Pipeline to Fuel Station Interface (Step-Out Phase)	Provides a physical interface between the fuel station and the Pipeline Distribution System. (Step-Out Phase)
Producer Remote Access Link to LCC	Provides a trusted link between the producer and the LCC to support hydrogen demand / supply reporting and load transaction information.
Production to Terminal Storage Hookup (Step-Out Phase)	Connects the Hydrogen Production System, operating at the Terminal, to the Terminal Storage System. (Step-Out Phase)
Remote Access Communications Links	Provides communications links back to the LCC.
Terminal Facility Remote Access Link to LCC	Provides Terminal Facility remote access to the LCC.
Terminal Storage to Pipeline Hookup (Step-Out Phase)	Provides a physical interface between the Terminal Storage System and the Pipeline Distribution System. (Step-Out Phase)
Transport Driver to Fuel Station Operator Interactions	Transport Driver to Fuel Station Link represents the Human-to Human voice communications between the Transport Driver and the Fuel Station Operator.
Transport Driver to Fuel Station Unload Compressor Interactions	Provides an interface between the Vehicle Transport Operator and the Fuel Station Unload Compressor.
Transport Driver to Producer	Transport Driver to Producer Link represents the Human-to-Human

Element	Definition
Operator Interactions	communications between the Transport Driver and the Producer Operator.
Transport Driver to Production Dispenser Interactions	Provides the Vehicle Transport Driver with an HMI to the Production Load Dispenser.
Transport Driver to Terminal Dispenser Interactions	Provides the Vehicle Transport Driver with an HMI to the Terminal Load Dispenser.
Transport Driver to Terminal Operator Interactions	Supports verbal communications between the Vehicle Transport Operator and the Terminal Operator.
Transport Driver to Terminal Unload Compressor Interactions	Provides the Vehicle Transport Driver with an HMI to the Terminal Unload Compressor.
Transport Vehicle to Storage System Hookup	Provides a physical interface between the Vehicle Transport Storage and the Fuel Station Unload Compressor.
Transport Vehicle to Terminal Dispenser Hookup	Provides the Vehicle Transport Driver with an HMI to the Terminal Load Dispenser.
Transport Vehicle to Terminal Storage Hookup	Provides the Vehicle Transport with a physical interface to the Terminal Storage System.
Vehicle Transport to Producer Dispenser Hookup	Provides a physical interface between the Vehicle Transport Storage and the Production Load Dispenser
Wide Area Network (Financial Institution)	Provides a Wide Area Network connection from the Fuel Station LAN to the Financial Institution.

Appendix B.11: Systems – Systems Matrix (SV-3)

Table 22. Systems – Systems Matrix (SV-3a)

	Compliance Systems	Delivery Management System (Logistics Command Center)	Forecourt Systems	Maintenance Systems	Terminal Systems	Vehicle Transport Systems	Additional Step-Out Phase System Components	Corporate Systems	Financial Institution	H2 FCV Consumer (Vehicle / Owner)	Position / Location System	Production Facility
Compliance Systems		X										
Delivery Management System (Logistics Command Center)	X		X	X	X	X		X				X
Forecourt Systems		X				X	X		X	X		
Maintenance Systems		X										
Terminal Systems		X				X	X					
Vehicle Transport Systems		X	X		X						X	X
Additional Step-Out Phase System Components			X		X							
Corporate Systems		X										
Financial Institution			X									
H2 FCV Consumer (Vehicle / Owner)			X									
Position / Location System						X						
Production Facility		X				X						

Table 23. Systems / Systems Matrix (SV-3a) Associated Element Definitions

Element	Definition
Component	
Additional Step-Out Phase System Components	The Hydrogen Delivery System Step-Out Phase transitions external production to the terminal facilities in order to flatten the distribution network, effectively lowering hydrogen delivery costs by bringing production closer to the retail fuel stations. It also potentially adds pipeline distribution in areas where there are right-of-ways (such as highways) and where there are not urban pressure restrictions. The Hydrogen Delivery System Step-Out Phase will be implemented as the H2 FCV market develops with the key decision point to go forward occurring in 2018, as H2 FCV market adoption starts to ramp up. The Hydrogen Delivery System for the Step-Out phase will be a more scalable and efficient architecture versus the Initial Phase due to the flattening of the distribution network and addition of pipeline distribution, but will require significant capital expenditures to co-locate hydrogen production at the terminals and to build out the pipeline infrastructure. The Hydrogen Delivery System for the Step-Out Phase includes the transport (vehicular and pipeline), storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Compliance Systems	
Corporate Systems	Corporate Systems is a collection of Information Systems which are a part of the corporate enterprise which support the functional organization.
Delivery Management System (Logistics Command Center)	The Delivery Management System is responsible for automating the management of the hydrogen supply, conformance to hydrogen fuel standards and maintenance of the Hydrogen Delivery System.
Financial Institution	The main role of the external financial institution in this architecture is to support transactions between the end consumers for hydrogen and the corporation.
Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
H2 FCV Consumer (Vehicle / Owner)	End consumer for H2 energy product being provided by the Hydrogen Delivery System.
Maintenance Systems	Compliance systems are used by systems maintainers in order to measure the system operational performance. This information is used by the maintainer to make repairs to the system or remediate non-conformation to operational requirements.
Position / Location System	A constellation of satellites called the Global Positioning System.

Element	Definition
Production Facility	The Production Facility is the source of Hydrogen Energy for the Hydrogen Delivery System. Located at the Production Facility are a Storage System and Load Dispenser capable of loading Vehicle Transports with Compressed Hydrogen Gas.
Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.

Appendix B.12: System / Services Functional Description (SV-4)

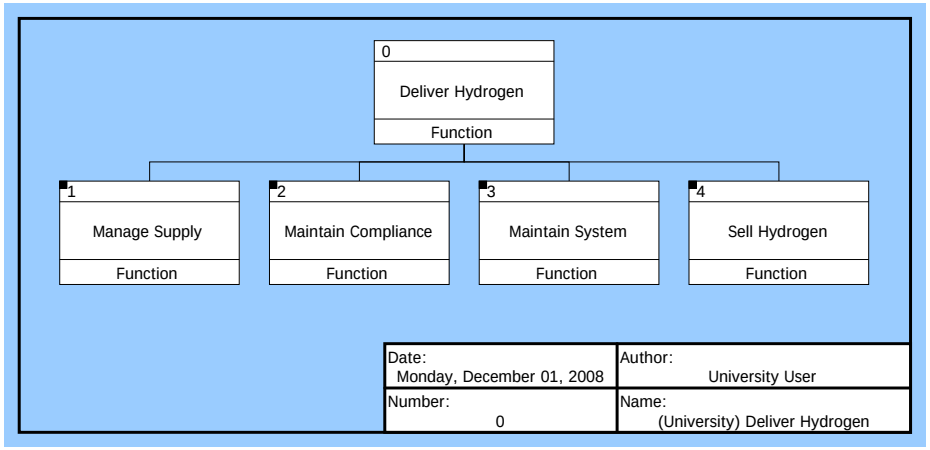

Figure 58. Deliver Hydrogen Hierarchy Diagram

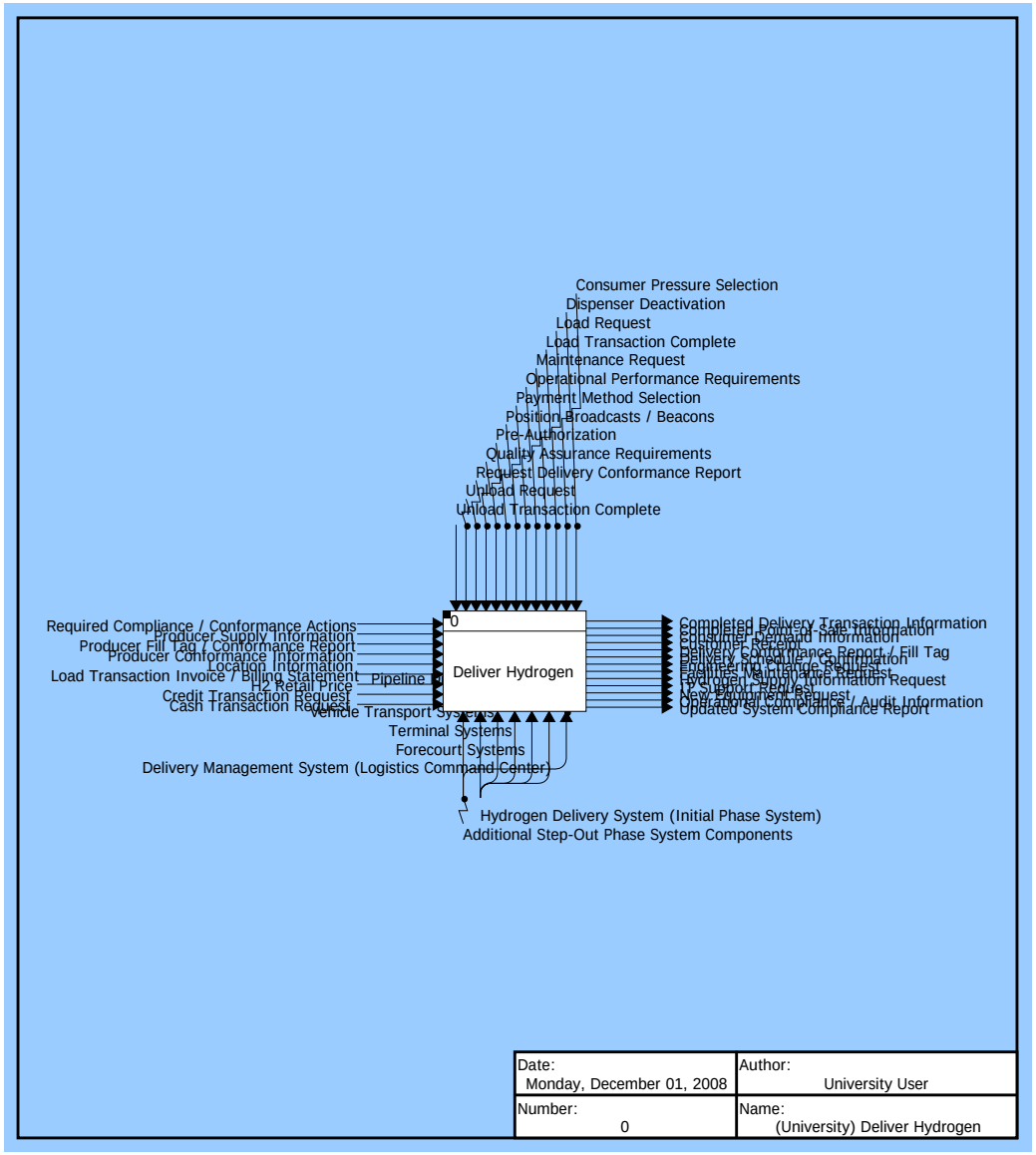

Figure 59. Deliver Hydrogen IDEF0 A-0 Context Diagram

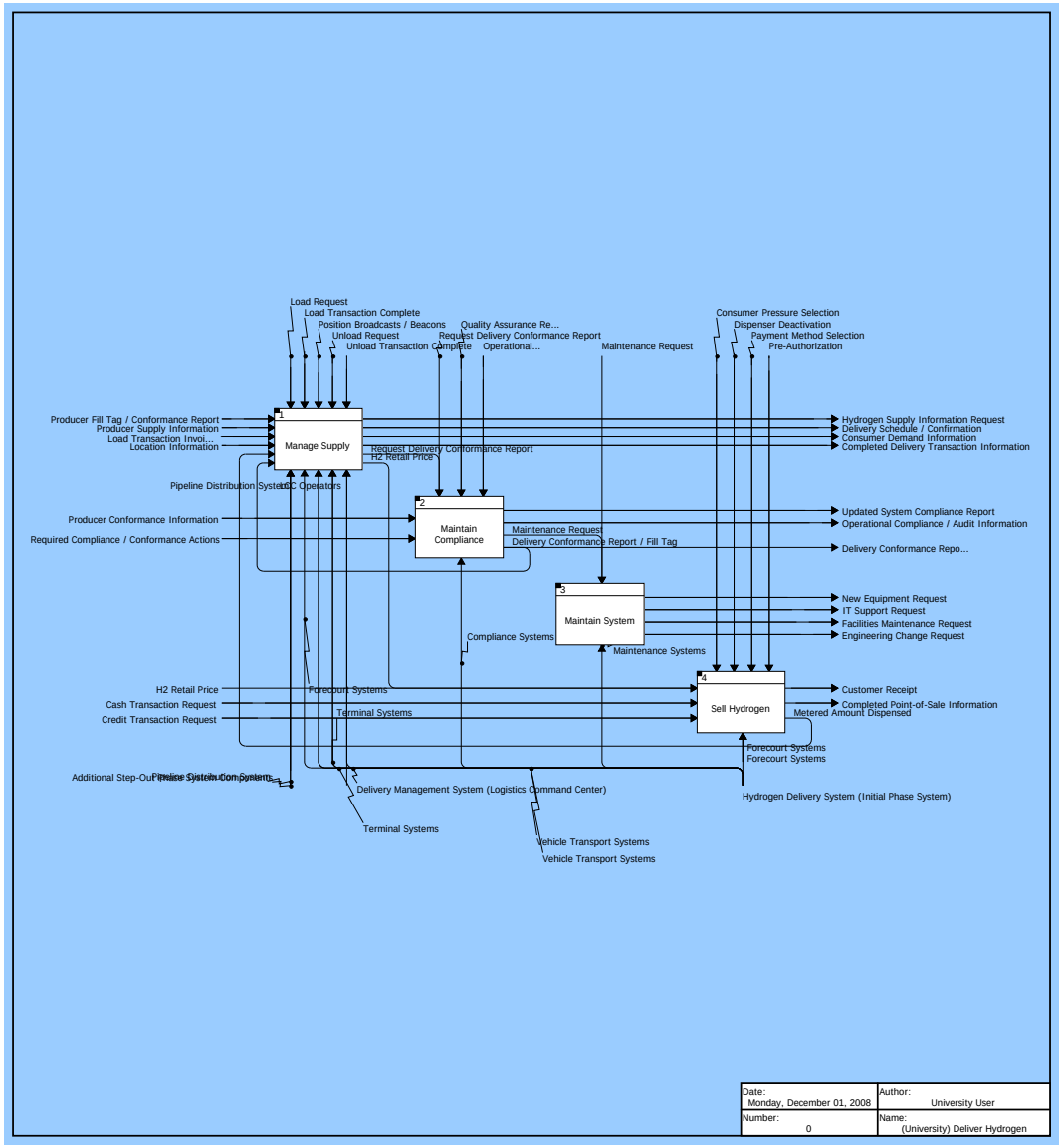

Figure 60. Deliver Hydrogen IDEF0 Diagram

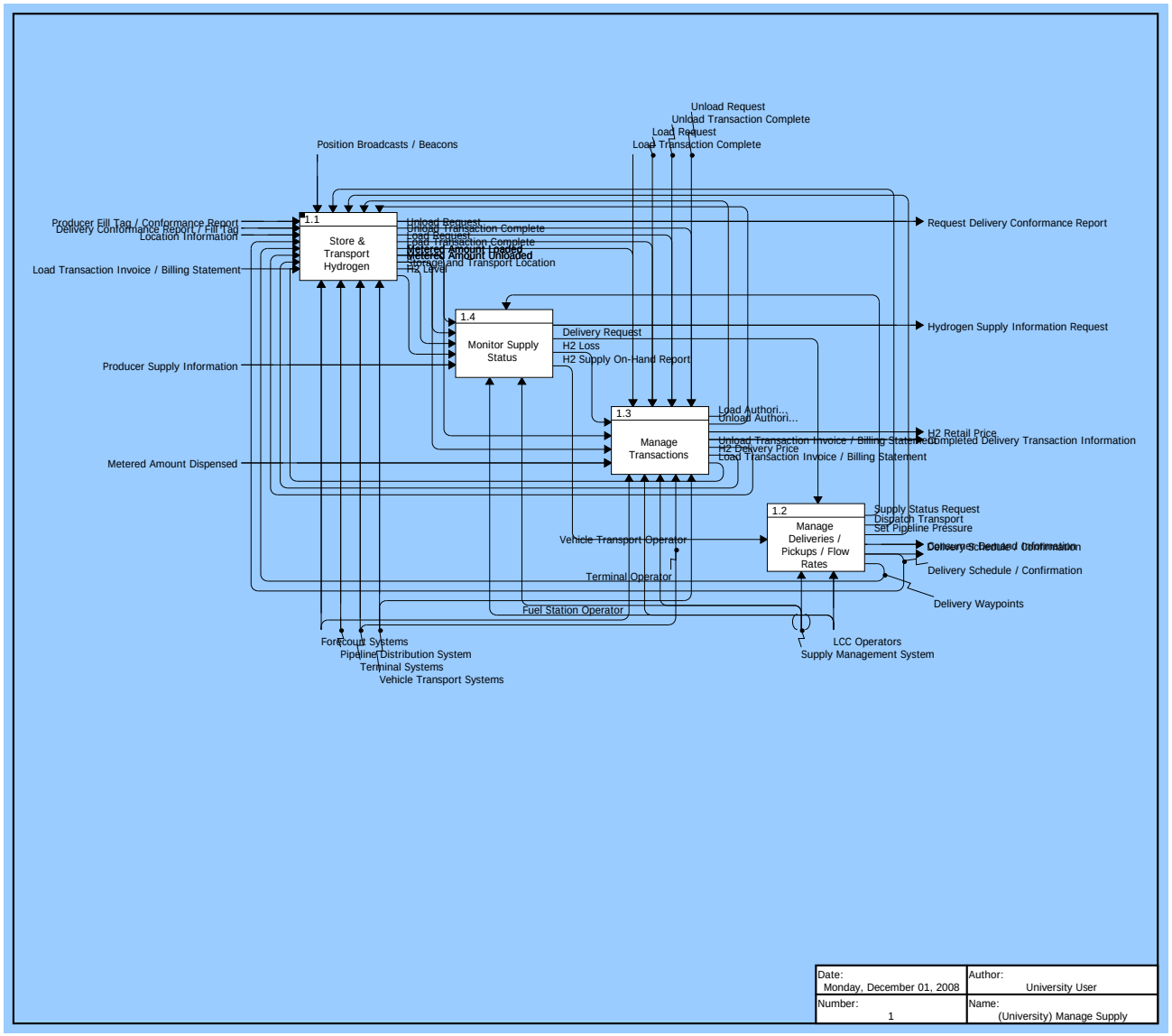

Figure 61. Manage Supply IDEF0 Diagram

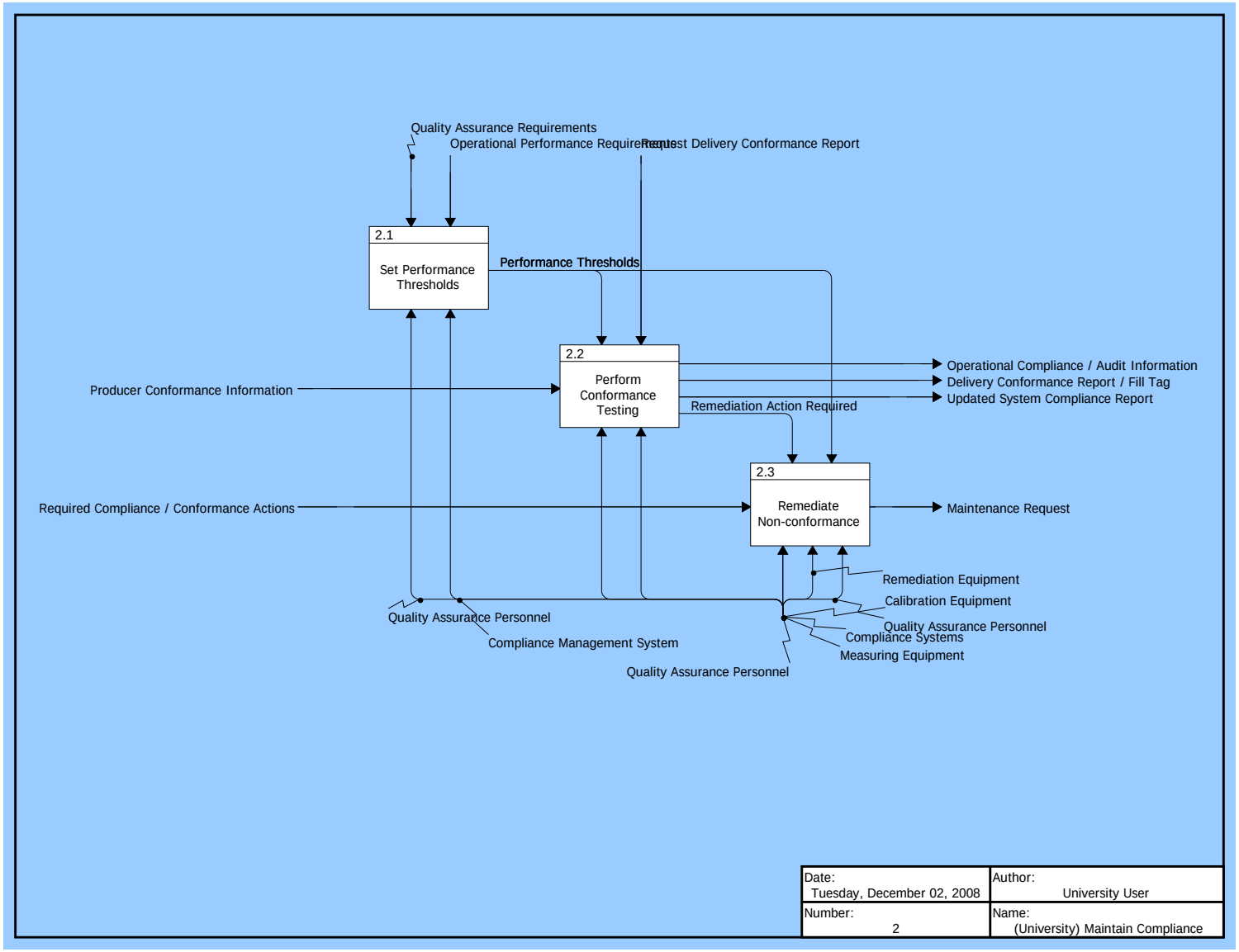

Figure 62. Maintain Compliance IDEF0 Diagram

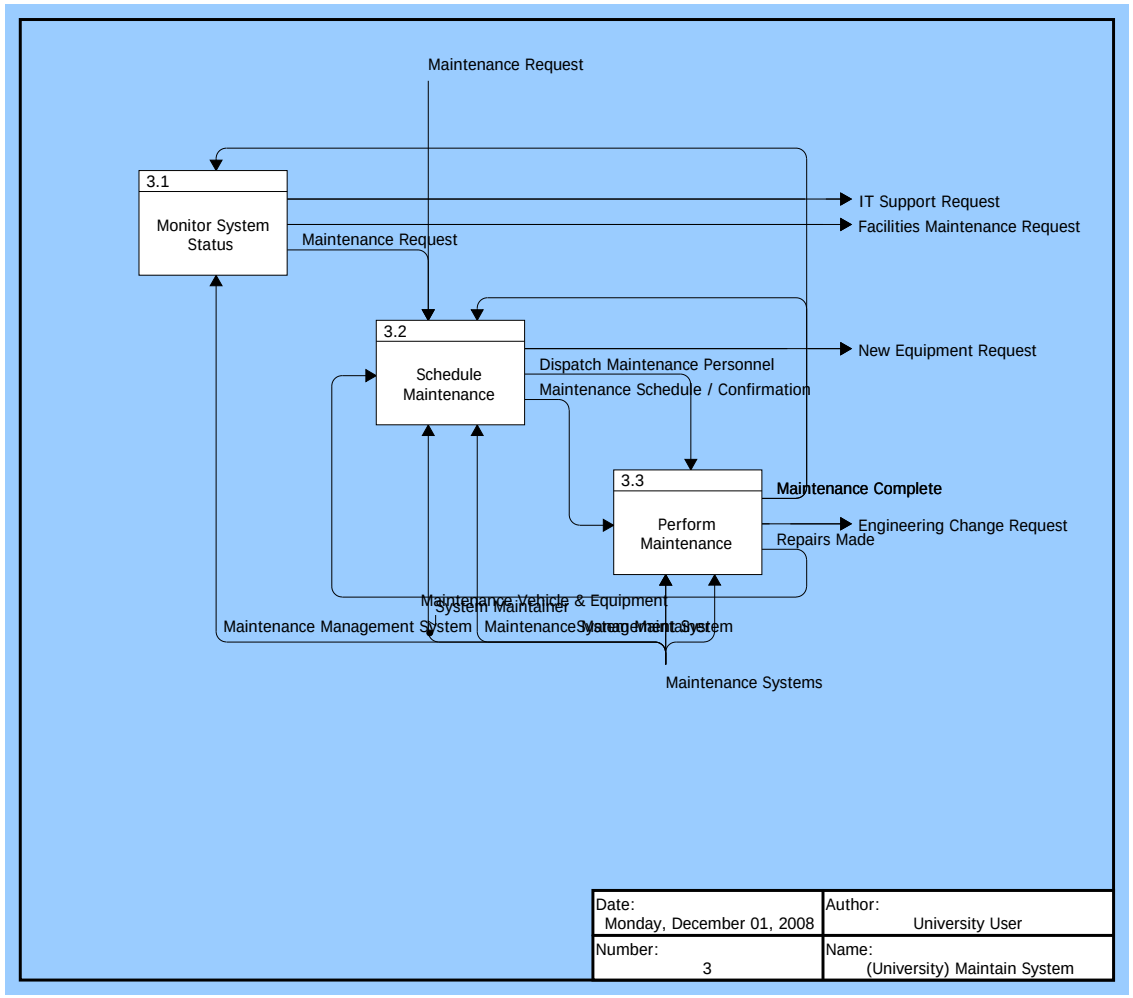

Figure 63. Maintain System IDEF0 Diagram

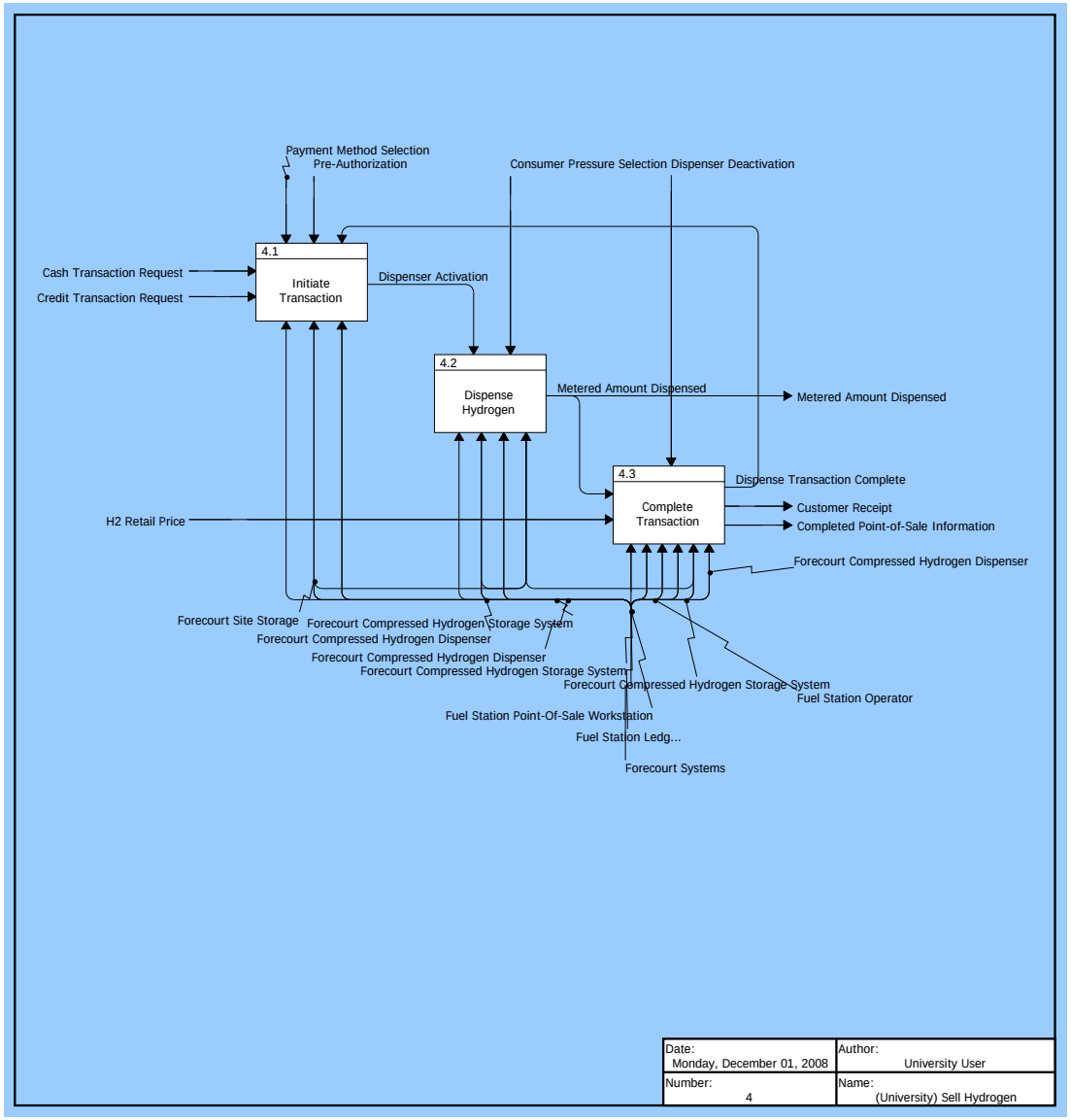

Figure 64. Sell Hydrogen IDEF0 Diagram

Table 24. Systems / Services Functionality Description (SV-4) Associated Element Definitions

Element	Definition
Component	
1 Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
1.1 Forecourt Compressed Hydrogen Storage System	The Forecourt Compressed Hydrogen Storage System is responsible for receiving, storing and monitoring the hydrogen supply at the fuel station.
1.1.3 Forecourt Site Storage	Forecourt Site Storage receives hydrogen from vehicle transport and provides hydrogen to the fuel dispenser.
1.2 Forecourt Compressed Hydrogen Dispenser	The Forecourt Compressed Hydrogen Dispenser is the point-of-sale for customers.
1.3 Fuel Station Operator	The Fuel Station Operator is responsible for managing fuel station operations.
1.4 Fuel Station Ledger System	The Fuel Station Ledger System maintains an electronic record of transactions local to the fuel station.
1.5 Fuel Station Point-Of-Sale Workstation	The Fuel Station Point-Of-Sale Workstation is used to manage transactions and monitor operations at the fuel station.
2 Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
2.3 Terminal Operator	The Fuel Station Operator is responsible for managing fuel station operations.
3 Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.
3.5 Vehicle Transport Operator	The Vehicle Transport Operator is responsible for the Vehicle Transport System and picking up and delivering hydrogen as requested by the LCC.
4 Delivery Management System (Logistics Command Center)	The Delivery Management System is responsible for automating the management of the hydrogen supply, conformance to hydrogen fuel standards and maintenance of the Hydrogen Delivery System.
4.1 Supply Management System	The Supply Management System manages the hydrogen supply across the Hydrogen Delivery System.
4.2 LCC Operators	LCC Operators are responsible for managing operations: supply management, maintenance management and compliance management.

Element	Definition
5 Pipeline Distribution System	Compressed H2 distribution pipeline takes gas from the terminal production facilities directly to retail fuel stations.
6 Maintenance Systems	Compliance systems are used by systems maintainers in order to measure the system operational performance. This information is used by the maintainer to make repairs to the system or remediate non-conformation to operational requirements.
6.1 System Maintainer	System Maintainer performs maintenance and remediation activities.
6.2 Maintenance Vehicle & Equipment	Maintenance Vehicle and Equipment are employed to maintain and repair the system.
6.5 Maintenance Management System	The Maintenance Management System monitors reports and tracks errors, faults, and failures in the system and is used to diagnose, track and close-out problems and manages repair requests made to maintenance personnel.
7 Compliance Systems	
7.1 Calibration Equipment	Calibration Equipment is used to calibrate non-compliance measuring systems.
7.2 Measuring Equipment	Measuring equipment is used by QA personnel to measure the performance of system components and quality of H2 supply.
7.3 Remediation Equipment	Remediation equipment employed to correct non-conforming systems or product (such as H2 purifier to address storage tank impurities).
7.4 Quality Assurance Personnel	Quality Assurance Personnel are required to measure the performance of systems and calibrate metering / measuring equipment.
7.5 Compliance Management System	The Compliance Management System is responsible for measuring and reporting system and hydrogen supply metrics against operational performance requirements.
Additional Step-Out Phase System Components	The Hydrogen Delivery System Step-Out Phase transitions external production to the terminal facilities in order to flatten the distribution network, effectively lowering hydrogen delivery costs by bringing production closer to the retail fuel stations. It also potentially adds pipeline distribution in areas where there are right-of-ways (such as highways) and where there are not urban pressure restrictions. The Hydrogen Delivery System Step-Out Phase will be implemented as the H2 FCV market develops with the key decision point to go forward occurring in 2018, as H2 FCV market adoption starts to ramp up. The Hydrogen Delivery System for the Step-Out phase will be a more scalable and efficient architecture versus the Initial Phase due to the flattening of the distribution network and addition of pipeline distribution, but will require significant capital expenditures to co-locate hydrogen production at the terminals and to build out the pipeline infrastructure. The Hydrogen Delivery System for the Step-Out Phase includes the transport (vehicular and pipeline), storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Hydrogen Delivery System	The Hydrogen Delivery System Initial Phase architecture supports a Centralized Production distribution model. Initial Phase

Element	Definition
(Initial Phase System)	Scenario: Production occurs at a large facility and delivered to a terminal facility for delivery to a fuel station. The Hydrogen Delivery System for the Initial Phase includes the transport, storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Item	
Cash Transaction Request	Cash Transaction Request is the payment method selected by the customer as an alternative to credit. This transaction will require Human-Human interaction between the customer and fuel station operator.
Completed Delivery Transaction Information	Completed Delivery Transaction Information consists of the metered amount of hydrogen delivered, location, on-site storage tank and time. This information is used by the system to update reports to finance and to manage the available supply on-hand. This information is also used in conjunction with tank sensor readings in order to understand hydrogen energy loss, which has both financial and operational significance.
Completed Point-of-Sale Information	Completed Point-of-Sale Information contains amount of hydrogen, price per Kg and total amount.
Consumer Demand Information	Consumer Demand Information is reported to the producer in order for the producer to meet current hydrogen consumption rates.
Consumer Pressure Selection	
Credit Transaction Request	Credit Transaction Request is the payment method selected by the customer which will require a financial institution in order to complete the transaction.
Customer Receipt	Customer Receipt contains completed transaction information - amount of H2, price per Kg and total amount either paid in cash or charged to credit.
Delivery Conformance Report / Fill Tag	The Delivery Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.
Delivery Request	Delivery Request is a request to schedule a delivery.
Delivery Schedule / Confirmation	Delivery schedules are generated by the LCC based on known supply. These schedules are periodically provided to fuel station and terminal operators in order to anticipate delivery time (origination). .
Delivery Waypoints	Delivery waypoints are used by drivers in addition to the onboard position / location system to follow predetermined hydrogen pickup and delivery routes.
Dispatch Maintenance	Dispatch Maintenance Personnel is a message that captures and describes a problem, remediation actions required (in addition to

Element	Definition
Personnel	specialized equipment required - if any), proposed repair times and assigns a priority to the problem. The priority is used by maintenance operations in order to schedule maintenance activities. This schedule is providing to the LCC and relevant system operators to manage around repairs which may cause operational impacts.
Dispatch Transport	Dispatch Transport is a trigger used to dispatch a vehicle transport to make a delivery.
Dispense Transaction Complete	Dispense Transaction Complete indicates that the dispenser is ready for another customer.
Dispenser Activation	Dispenser Activation is a signal sent by the fuel station operator / system to activate the pump if the customer is authorized.
Dispenser Deactivation	Dispenser Deactivation is a signal deactivating the dispenser when the customer places the dispenser nozzle back into the pump.
Engineering Change Request	Contains details pertaining to system design updates, such as the description of the flaw, how it impacts operations, any steps taken to remediate or address the problem previously and recommended or requested changes that need to be made to the system. Minor design changes are required to address flaws which impact system triggers this request.
Facilities Maintenance Request	Facilities Maintenance Requests are made when the condition of company-owned facilities or property affects the operation of the overall system.
H2 Delivery Price	The price of hydrogen delivered to be used to generate billing statements, invoices.
H2 Level	H2 Level is calculated using a tank pressure sensor reading and the size of the tank and is report to the manage supply function.
H2 Loss	H2 Loss is the amount of Hydrogen Energy which is lost over any given period of time.
H2 Retail Price	H2 Retail Price is the price at which the fuel station will sell hydrogen. This value is based on the invoiced delivery cost and fuel station markup. The fuel station markup is based on financial performance objectives and guidance.
H2 Supply On-Hand Report	A report of available H2 supply in the delivery system down to the individual terminal, fuel station and vehicle tank.
Hydrogen Supply Information Request	Request to the producer to provide information regarding available hydrogen supply on-hand (stored) and current operating capacity.
IT Support Request	IT Support Requests are made when company-owned Information Technology asset failure affects the overall operation of the system.
Load Authorization	Load Authorization is a signal used to activate the dispenser.
Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.
Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.
Load Transaction Invoice / Billing Statement	The Load Transaction Invoice is issued by the producer and terminal operator upon receipt of hydrogen. This statement is used to complete a B2B transaction with the producer or terminal operations (if required as a part of an exchange arrangement) or used to update ledger information in the terminal operations which is reported up to the LCC and corporation to pay the

Element	Definition
	producer and/or update the books.
Location Information	Location Information contains absolute location information using a latitude and longitude coordinate system.
Maintenance Complete	Maintenance Complete is a message that is a positive acknowledgement to a maintenance request, providing the start / end time of the repair and any downtime, the repair actions, equipment used and parts required, maintenance personnel name and identification number. It also indicates any follow up maintenance or repairs that may be required.
Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.
Maintenance Schedule / Confirmation	Maintenance required is used to communicate the repair action and locations required and act as a confirmation to the maintenance request.
Metered Amount Dispensed	Metered Amount Dispensed is the amount of hydrogen dispensed as detected by the meter on the dispenser. This information is used to complete transactions.
Metered Amount Loaded	Metered Amount Loaded is the amount of hydrogen in Kg which has been loaded on the vehicle transport.
Metered Amount Unloaded	Metered Amount Unloaded is the amount of hydrogen which has been delivered either to the terminal or fuel station facility.
New Equipment Request	New Equipment Request is sent when new parts or equipment is required be made (manufacturing) or purchased (procurement) to support maintenance operations.
Operational Compliance / Audit Information	Information from internal audits is reported back to corporate operations.
Operational Performance Requirements	Operation Performance Parameters are key performance parameters and required performance ranges in order to maintain compliance.
Payment Method Selection	Payment Method Selection is made by the customer at the fuel station pump / dispenser.
Performance Thresholds	Performance thresholds specify operational ranges for key system performance parameters.
Position Broadcasts / Beacons	Position Broadcasts / Beacons are signals provided by external systems in order to locate vehicle transport and maintenance vehicles.
Pre-Authorization	Pre-Authorization is a message that is used to activate the dispenser. Pre-authorization may be granted by the financial institution if credit was selected or by the fuel station operator if cash was selected.
Producer Conformance Information	H2 Conformance Information is conformance information provided to ongoing compliance functions in order to ensure that all hydrogen being delivered or stored meets operational requirements.
Producer Fill Tag / Conformance Report	
Producer Supply Information	Producer Supply Information indicates the available supply of stored hydrogen at the production site and the rate at which

Element	Definition
	hydrogen is being produced.
Quality Assurance Requirements	Quality Assurance Requirements is a message placeholder for all requirements placed on the system during operation which further constrain system operation.
Remediation Action Required	Remediation action required is an action required to remediate non-compliance or non-conformance with operational performance parameters. This could require a repair, recalibration or some other action such as hydrogen purification.
Repairs Made	Repairs made is a positive acknowledgement that the repairs that were scheduled were made, the time of repair and resulting downtime (if-any), repair action and affected systems.
Request Delivery Conformance Report	Request Delivery Conformance Report is a mechanism for the Management Supply function to trigger the Maintain Compliance function to report out the latest compliance information for the entire system or individual system components.
Required Compliance / Conformance Actions	Actions to remediate non-compliant system operation.
Set Pipeline Pressure	Set Pipeline Pressure sets the pressure on the pipeline controlling the flow of hydrogen through the pipeline distribution system.
Storage and Transport Location	
Supply Status Request	Supply Status Request is a mechanism used to trigger storage systems to report out supply information.
Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.
Unload Request	The Vehicle Transport Operator makes Unload Requests of the Terminal or Fuel Station Operator prior to the unload compressor being activated.
Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.
Unload Transaction Invoice / Billing Statement	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.
Updated System Compliance Report	Updated System Compliance Report is sent to corporate operations.

Appendix B.13: Operational Activity to Systems Function Traceability Matrix (SV-5)

Table 25. Operational Activity to Systems Function Traceability Matrix (SV-5)

Component	Function	Operational Activity				
		Manage Supply Operations	Perform Fuel Station Operations	Perform Maintenance & Compliance Operations	Perform Terminal Operations	Store & Transport Hydrogen
Compliance Systems	Maintain Compliance			X		
Delivery Management System (Logistics Command Center)	Deliver Hydrogen	X	X	X	X	X
Forecourt Systems	Complete Transaction					
	Deliver Hydrogen	X	X	X	X	X
	Dispense Hydrogen					
	Initiate Transaction					
	Manage Supply	X			X	X
	Sell Hydrogen		X			
	Store & Transport Hydrogen					X
	Unload Transport					X

Component	Function	Operational Activity				
		Manage Supply Operations	Perform Fuel Station Operations	Perform Maintenance & Compliance Operations	Perform Terminal Operations	Store & Transport Hydrogen
Maintenance Systems	Maintain System			**X**	**X**	
Terminal Systems	Deliver Hydrogen	**X**	**X**	**X**	**X**	**X**
	Load Transport					**X**
	Manage Supply	**X**			**X**	**X**
	Store & Transport Hydrogen					**X**
	Unload Transport					**X**
Vehicle Transport Systems	Deliver Hydrogen	**X**	**X**	**X**	**X**	**X**
	Manage Supply	**X**			**X**	**X**
	Move Empty Transport					**X**
	Move Hydrogen					**X**
	Store & Transport Hydrogen					**X**
	Unload Transport					**X**

Table 26. Operational Activity to Systems Function Traceability Matrix (SV-5) Associated Element Definitions

Element	Definition
Component	
Compliance Systems	
Delivery Management System (Logistics Command Center)	The Delivery Management System is responsible for automating the management of the hydrogen supply, conformance to hydrogen fuel standards and maintenance of the Hydrogen Delivery System.
Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
Hydrogen Delivery System (Initial Phase System)	The Hydrogen Delivery System Initial Phase architecture supports a Centralized Production distribution model. Initial Phase Scenario: Production occurs at a large facility and delivered to a terminal facility for delivery to a fuel station. The Hydrogen Delivery System for the Initial Phase includes the transport, storage and sale of hydrogen at company terminals and fuel stations. It requires a Logistics Command Center to manage delivery operations and maintenance. It does not include production equipment or production facilities or the H2 FCV's where the hydrogen is converted and applied.
Maintenance Systems	Compliance systems are used by systems maintainers in order to measure the system operational performance. This information is used by the maintainer to make repairs to the system or remediate non-conformation to operational requirements.
Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.
Function	
Complete Transaction	Completes the sales transaction based on the hydrogen retail price and the amount of hydrogen dispensed.
Deliver Hydrogen	Performs the Delivery Hydrogen Energy mission.
Dispense Hydrogen	Dispenses hydrogen when authorized. Meters the dispensed hydrogen.
Initiate Transaction	Initiates the dispenser based on customer input: selected payment method, pressure.
Load Transport	The Load Transport function is responsible for, 1. Initiating the Load Transaction 2. Loading the transport with hydrogen 3. Completing the load transaction

Element	Definition
Maintain Compliance	The Maintain Compliance function is responsible for setting performance thresholds for operational components, testing and measuring the system components against those thresholds and performing tasks to remediate any non-compliance, non-conforming equipment or hydrogen product.
Maintain System	The Maintain System function is responsible for monitoring, maintaining and repairing operational systems and components.
Manage Supply	Manage Supply function is responsible for the flow of hydrogen through the Hydrogen Delivery System.
Move Empty Transport	The Move Empty Transport function is responsible for positioning empty transports at producer or terminal locations in order to accept a load of hydrogen energy.
Move Hydrogen	The Move Hydrogen function is responsible for transporting the delivery vehicle to terminal or fuel station destinations.
Sell Hydrogen	The Sell Hydrogen function is responsible for the retail sale of hydrogen.
Store & Transport Hydrogen	The Store & Transport Hydrogen function is responsible for the transport and storage of hydrogen across the Hydrogen Delivery System.
Unload Transport	The Unload Transport function is responsible for, 1. Initiating the Unload Transaction 2. Unloading transport storage 3. Completing the unload transaction
OperationalActivity	
Deliver Hydrogen	Delivery Hydrogen Operational Activity is responsible for the Delivery of Hydrogen energy from the Producer to the H2 FCV Customer.
Manage Supply Operations	Manage Supply Operations is carried out by the LCC and is responsible for the overall management of all supply, maintenance and compliance activities in addition to supply transactions carried out at the producer, terminal and fuel station facilities.
Perform Fuel Station Operations	Perform Fuel Station Operations Operational Activity is responsible for the operational activities local to the fuel station including supply transactions, hydrogen sales and low-level maintenance of the facilities.
Perform Maintenance & Compliance Operations	Perform Maintenance & Compliance Operations is responsible for all maintenance and compliance activities that occur across the system.
Perform Terminal Operations	Perform Terminal Operations Operation Activity is responsible for the management of operations local to the terminal facility.
Store & Transport Hydrogen	The Store & Transport Hydrogen Operational Activity is responsible for moving hydrogen energy through the supply chain.

Appendix B.14: Systems / Services Data Exchange Matrix (SV-6)

Table 27. Systems / Services Data Exchange Matrix (SV-6)

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
CMS to LCC Link	Remediation Action Required	Remediation action required is an action required to remediate non-compliance or non-conformance with operational performance parameters. This could require a repair, recalibration or some other action such as hydrogen purification.		Compliance Systems *Perform Conformance Testing*	Compliance Systems *Remediate Non-conformance*
Corporate Intranet	Completed Delivery Transaction Information	Completed Delivery Transaction Information consists of the metered amount of hydrogen delivered, location, on-site storage tank and time. This information is used by the system to update reports to finance and to manage the available supply on-hand. This information is also used in conjunction with tank sensor readings in order to understand hydrogen energy loss, which has both financial and operational significance.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Corporate Systems *Maintain Financial System*
	Engineering Change Request	Contains details pertaining to system design updates, such as the description of the flaw,		Delivery Management System (Logistics Command Center)	Corporate Systems *Develop & Modify System*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		how it impacts operations, any steps taken to remediate or address the problem previously and recommended or requested changes that need to be made to the system. Minor design changes are required to address flaws which impact system triggers this request.		*Deliver Hydrogen*	
	Facilities Maintenance Request	Facilities Maintenance Requests are made when the condition of company-owned facilities or property affects the operation of the overall system.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Corporate Systems *Repair Facility*
	IT Support Request	IT Support Requests are made when company-owned Information Technology asset failure affects the overall operation of the system.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Corporate Systems *Provide IT Support*
	New Equipment Request	New Equipment Request is sent when new parts or equipment is required be made (manufacturing) or purchased (procurement) to support maintenance operations.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Corporate Systems *Purchase Equipment* *Build Equipment*
	Operational Compliance / Audit Information	Information from internal audits is reported back to corporate operations.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Corporate Systems *Enforce Operational Compliance*
	Operational	Operation Performance		Corporate Systems	Delivery Management

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
	Performance Requirements	Parameters are key performance parameters and required performance ranges in order to maintain compliance.		*Enforce Operational Compliance*	System (Logistics Command Center) *Deliver Hydrogen*
	Program Management Status Report			Delivery Management System (Logistics Command Center) *Monitor Supply Status*	Corporate Systems *Manage Program*
	Quality Assurance Requirements	Quality Assurance Requirements is a message placeholder for all requirements placed on the system during operation which further constrain system operation.		Compliance Systems *Set Performance Thresholds*	Delivery Management System (Logistics Command Center) *Deliver Hydrogen*
	Required Compliance / Conformance Actions	Actions to remediate non-compliant system operation.		Compliance Systems *Remediate Non-Conformance*	Delivery Management System (Logistics Command Center) *Deliver Hydrogen*
	Updated System Compliance Report	Updated System Compliance Report is sent to corporate operations.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Compliance Systems *Perform Conformance Testing*
Customer to Fuel Station Dispenser HMI	Customer Receipt	Customer Receipt contains completed transaction information - amount of H2, price per Kg and total amount either paid in cash or charged to credit.		Forecourt Systems *Deliver Hydrogen*	Sell Hydrogen *Complete Transaction*
	Payment Method Selection	Payment Method Selection is made by the customer at the fuel station pump / dispenser.		Sell Hydrogen *Complete Transaction*	Forecourt Systems *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
Customer to Fuel Station Operator Interactions	Customer Receipt	Customer Receipt contains completed transaction information - amount of H2, price per Kg and total amount either paid in cash or charged to credit.		Forecourt Systems *Deliver Hydrogen*	Sell Hydrogen *Complete Transaction*
Fuel Station Remote Access Link to LCC	Completed Delivery Transaction Information	Completed Delivery Transaction Information consists of the metered amount of hydrogen delivered, location, on-site storage tank and time. This information is used by the system to update reports to finance and to manage the available supply on-hand. This information is also used in conjunction with tank sensor readings in order to understand hydrogen energy loss, which has both financial and operational significance.		Forecourt Systems *Deliver Hydrogen*	Corporate Systems *Maintain Financial System*
	Completed Point-of-Sale Information	Completed Point-of-Sale Information contains amount of hydrogen, price per Kg and total amount.		Forecourt Systems *Deliver Hydrogen*	Financial Institution *Provide Credit*
	Credit Request	Request made by the consumer for credit pre-authorization required prior to dispenser activation.		H2 FCV Consumer *Purchase Hydrogen*	Financial Institution *Provide Credit*
	Delivery Schedule / Confirmation	Delivery schedules are generated by the LCC based on known supply. These schedules are periodically		Forecourt Systems *Deliver Hydrogen*	Forecourt Systems *Store & Transport Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		provided to fuel station and terminal operators in order to anticipate delivery time (origination). .			
	H2 Delivery Price	The price of hydrogen delivered to be used to generate billing statements, invoices.		Forecourt Systems *Manage Transactions*	Forecourt Systems *Store & Transport Hydrogen*
	Maintenance Schedule / Confirmation	Maintenance required is used to communicate the repair action and locations required and act as a confirmation to the maintenance request.		Maintenance Systems *Schedule Maintenance*	Maintenance Systems *Perform Maintenance*
	Pre-Authorization	Pre-Authorization is a message that is used to activate the dispenser. Pre-authorization may be granted by the financial institution if credit was selected or by the fuel station operator if cash was selected.		Financial Institution *Provide Credit*	Forecourt Systems *Deliver Hydrogen*
	Repairs Made	Repairs made is a positive acknowledgement that the repairs that were scheduled were made, the time of repair and resulting downtime (if-any), repair action and affected systems.		Maintenance Systems *Perform Maintenance*	Maintenance Systems *Schedule Maintenance*
	Storage and Transport Location			Forecourt Systems *Store & Transport Hydrogen*	Delivery Management System (Logistics Command Center) *Monitor Supply Status*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
	Supply Status Request	Supply Status Request is a mechanism used to trigger storage systems to report out supply information.		Delivery Management System (Logistics Command Center) *Manage Deliveries / Pickups / Flow Rates*	Delivery Management System (Logistics Command Center) *Monitor Supply Status*
GPS Broadcast Satellite Link	Position Broadcasts / Beacons	Position Broadcasts / Beacons are signals provided by external systems in order to locate vehicle transport and maintenance vehicles.		Position / Location System *Provide Location Information*	Vehicle Transport Systems *Monitor Hydrogen Location and Amount*
Producer Remote Access Link to LCC	Consumer Demand Information	Consumer Demand Information is reported to the producer in order for the producer to meet current hydrogen consumption rates.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Production Facility *Provide Hydrogen*
	Delivery Schedule / Confirmation	Delivery schedules are generated by the LCC based on known supply. These schedules are periodically provided to fuel station and terminal operators in order to anticipate delivery time (origination). .		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Production Facility *Provide Hydrogen*
	Hydrogen Supply Information Request	Request to the producer to provide information regarding available hydrogen supply on-hand (stored) and current operating capacity.		Delivery Management System (Logistics Command Center) *Deliver Hydrogen*	Production Facility *Provide Hydrogen*
	Load Transaction Invoice / Billing Statement	The Load Transaction Invoice is issued by the producer and terminal operator upon receipt of		Delivery Management System (Logistics Command Center) *Manage Transactions*	Delivery Management System (Logistics Command Center) *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		hydrogen. This statement is used to complete a B2B transaction with the producer or terminal operations (if required as a part of an exchange arrangement) or used to update ledger information in the terminal operations which is reported up to the LCC and corporation to pay the producer and/or update the books.			
	Metered Amount Loaded	Metered Amount Loaded is the amount of hydrogen in Kg which has been loaded on the vehicle transport.		Production Facility *Provide Hydrogen*	Delivery Management System (Logistics Command Center) *Manage Transactions* Delivery Management System (Logistics Command Center) *Monitor Supply Status*
	Producer Conformance Information	H2 Conformance Information is conformance information provided to ongoing compliance functions in order to ensure that all hydrogen being delivered or stored meets operational requirements.		Production Facility *Provide Hydrogen*	Delivery Management System (Logistics Command Center) *Deliver Hydrogen*
	Producer Supply Information	Producer Supply Information indicates the available supply of stored hydrogen at the production site and the rate at which hydrogen is being		Production Facility *Provide Hydrogen*	Delivery Management System (Logistics Command Center) *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		produced.			
Remote Access Communications Links	Delivery Schedule / Confirmation	Delivery schedules are generated by the LCC based on known supply. These schedules are periodically provided to fuel station and terminal operators in order to anticipate delivery time (origination). .		Vehicle Transport Systems *Deliver Hydrogen*	Vehicle Transport Systems *Store & Transport Hydrogen*
	Delivery Waypoints	Delivery waypoints are used by drivers in addition to the onboard position / location system to follow predetermined hydrogen pickup and delivery routes.		Delivery Management System (Logistics Command Center) *Manage Deliveries / Pickups / Flow Rates*	Vehicle Transport Systems *Store & Transport Hydrogen*
	Dispatch Transport	Dispatch Transport is a trigger used to dispatch a vehicle transport to make a delivery.		Delivery Management System (Logistics Command Center) *Manage Deliveries / Pickups / Flow Rates*	Vehicle Transport Systems *Store & Transport Hydrogen*
	H2 Delivery Price	The price of hydrogen delivered to be used to generate billing statements, invoices.		Vehicle Transport Systems *Manage Transactions*	Vehicle Transport Systems *Store & Transport Hydrogen*
	Location Information	Location Information contains absolute location information using a latitude and longitude coordinate system.		Position / Location System *Position Location Information*	Vehicle Transport Systems *Deliver Hydrogen*
	Storage and Transport Location			Vehicle Transport Systems *Store & Transport Hydrogen*	Delivery Management System (Logistics Command Center)

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
					Monitor Supply Status
Terminal Facility Remote Access Link to LCC	Completed Delivery Transaction Information	Completed Delivery Transaction Information consists of the metered amount of hydrogen delivered, location, on-site storage tank and time. This information is used by the system to update reports to finance and to manage the available supply on-hand. This information is also used in conjunction with tank sensor readings in order to understand hydrogen energy loss, which has both financial and operational significance.		Terminal Systems *Deliver Hydrogen*	Corporate *Maintain Financial System*
	Delivery Schedule / Confirmation	Delivery schedules are generated by the LCC based on known supply. These schedules are periodically provided to fuel station and terminal operators in order to anticipate delivery time (origination). .		Terminal Systems *Deliver Hydrogen*	Terminal Systems *Store & Transport Hydrogen*
	Dispatch Maintenance Personnel	Dispatch Maintenance Personnel is a message that captures and describes a problem, remediation actions required (in addition to specialized equipment required - if any), proposed repair times and assigns a priority to the problem. The		Maintenance Systems *Schedule Maintenance*	Maintenance Systems *Perform Maintenance*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		priority is used by maintenance operations in order to schedule maintenance activities. This schedule is providing to the LCC and relevant system operators to manage around repairs which may cause operational impacts.			
	Dispatch Transport	Dispatch Transport is a trigger used to dispatch a vehicle transport to make a delivery.		Delivery Management System (Logistics Command Center) *Manage Deliveries / Pickups / Flow Rates*	Terminal Systems *Store & Transport Hydrogen*
	H2 Delivery Price	The price of hydrogen delivered to be used to generate billing statements, invoices.		Terminal Systems *Manage Transactions*	Terminal Systems *Store & Transport Hydrogen*
	Load Transaction Invoice / Billing Statement	The Load Transaction Invoice is issued by the producer and terminal operator upon receipt of hydrogen. This statement is used to complete a B2B transaction with the producer or terminal operations (if required as a part of an exchange arrangement) or used to update ledger information in the terminal operations which is reported up to the LCC and corporation to pay the producer and/or update the books.		Terminal Systems *Manage Transactions*	Terminal Systems *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
	Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.		Terminal Systems *Monitor System Status*	Maintenance Systems *Schedule Maintenance*
	Producer Conformance Information	H2 Conformance Information is conformance information provided to ongoing compliance functions in order to ensure that all hydrogen being delivered or stored meets operational requirements.		Production Facility *Provide Hydrogen*	Terminal Systems *Deliver Hydrogen*
	Repairs Made	Repairs made is a positive acknowledgement that the repairs that were scheduled were made, the time of repair and resulting downtime (if-any), repair action and affected systems.		Maintenance Systems *Perform Maintenance*	Maintenance Systems *Schedule Maintenance*
	Set Pipeline Pressure	Set Pipeline Pressure sets the pressure on the pipeline controlling the flow of hydrogen through the pipeline distribution system.		Delivery Management System (Logistics Command Center) *Manage Deliveries / Pickups / Flow Rates*	Terminal Systems *Store & Transport Hydrogen*
	Storage and Transport Location	Location of the Storage Tanks		Terminal Systems *Store & Transport Hydrogen*	Delivery Management System (Logistics Command Center) *Monitor Supply Status*
	Supply Status	Supply Status Request is a		Delivery Management	Delivery Management

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
	Request	mechanism used to trigger storage systems to report out supply information.		System (Logistics Command Center) *Manage Deliveries / Pickups / Flow Rates*	System (Logistics Command Center) *Monitor Supply Status*
Transport Driver to Fuel Station Operator Interactions	Delivery Conformance Report / Fill Tag	The Delivery Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.		Forecourt Systems *Deliver Hydrogen*	Forecourt Systems *Manage Supply*
	Metered Amount Unloaded	Metered Amount Unloaded is the amount of hydrogen which has been delivered either to the terminal or fuel station facility.		Forecourt Systems *Store & Transport Hydrogen*	Forecourt Systems *Manage Transactions*
	Request Delivery Conformance Report	Request Delivery Conformance Report is a mechanism for the Management Supply function to trigger the Maintain Compliance function to report out the latest compliance information for the entire system or individual system components.		Forecourt Systems *Manage Supply*	Forecourt Systems *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
	Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.		Forecourt Systems *Manage Transactions*	Forecourt Systems *Store & Transport Hydrogen*
	Unload Request	The Vehicle Transport Operator makes Unload Requests of the Terminal or Fuel Station Operator prior to the unload compressor being activated.		Forecourt Systems *Store & Transport Hydrogen*	Forecourt Systems *Deliver Hydrogen*
	Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.		Forecourt Systems *Store & Transport Hydrogen*	Forecourt Systems *Deliver Hydrogen*
	Unload Transaction Invoice / Billing Statement	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the		Forecourt Systems *Manage Transactions*	Forecourt Systems *Store & Transport Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		terminal or fuel station (if required) and/or update the books.			
Transport Driver to Fuel Station Unload Compressor Interactions	Metered Amount Unloaded	Metered Amount Unloaded is the amount of hydrogen which has been delivered either to the terminal or fuel station facility.		Forecourt Systems *Store & Transport Hydrogen*	Forecourt Systems *Manage Transactions*
	Unload Request	The Vehicle Transport Operator makes Unload Requests of the Terminal or Fuel Station Operator prior to the unload compressor being activated.		Forecourt Systems *Store & Transport Hydrogen*	Forecourt Systems *Deliver Hydrogen*
	Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.		Forecourt Systems *Store & Transport Hydrogen*	Forecourt Systems *Deliver Hydrogen*
	Unload Transaction Invoice / Billing Statement	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used		Forecourt Systems *Manage Transactions*	Forecourt Systems *Store & Transport Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.			
Transport Driver to Producer Operator Interactions	Load Authorization	Load Authorization is a signal used to activate the dispenser.		Vehicle Transport Systems *Manage Transactions*	Vehicle Transport Systems *Store & Transport Hydrogen*
	Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.		Vehicle Transport Systems *Store & Transport Hydrogen*	Vehicle Transport Systems *Deliver Hydrogen*
	Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.		Vehicle Transport Systems *Store & Transport Hydrogen*	Vehicle Transport Systems *Deliver Hydrogen*
	Load Transaction Invoice / Billing Statement	The Load Transaction Invoice is issued by the producer and terminal operator upon receipt of hydrogen. This statement is used to complete a B2B transaction with the producer or terminal operations (if required as a part of an exchange arrangement) or used to update ledger information in the terminal operations which is reported		Vehicle Transport Systems *Manage Transactions*	Vehicle Transport Systems *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		up to the LCC and corporation to pay the producer and/or update the books.			
	Metered Amount Loaded	Metered Amount Loaded is the amount of hydrogen in Kg which has been loaded on the vehicle transport.		Vehicle Transport Systems *Store & Transport Hydrogen*	Vehicle Transport Systems *Manage Transactions*
	Producer Conformance Information	H2 Conformance Information is conformance information provided to ongoing compliance functions in order to ensure that all hydrogen being delivered or stored meets operational requirements.		Production Facility *Provide Hydrogen*	Vehicle Transport Systems *Deliver Hydrogen*
	Producer Fill Tag / Conformance Report			Production Facility *Provide Hydrogen*	Vehicle Transport Systems *Deliver Hydrogen*
Transport Driver to Production Dispenser Interactions	Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.		Vehicle Transport Systems *Store & Transport Hydrogen*	Vehicle Transport Systems *Deliver Hydrogen*
	Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.		Vehicle Transport Systems *Store & Transport Hydrogen*	Vehicle Transport Systems *Deliver Hydrogen*
	Metered Amount Loaded	Metered Amount Loaded is the amount of hydrogen in Kg which has been loaded on the vehicle transport.		Vehicle Transport Systems *Store & Transport Hydrogen*	Vehicle Transport Systems *Manage Transactions*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
Transport Driver to Terminal Dispenser Interactions	Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Deliver Hydrogen*
	Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Deliver Hydrogen*
	Load Transaction Invoice / Billing Statement	The Load Transaction Invoice is issued by the producer and terminal operator upon receipt of hydrogen. This statement is used to complete a B2B transaction with the producer or terminal operations (if required as a part of an exchange arrangement) or used to update ledger information in the terminal operations which is reported up to the LCC and corporation to pay the producer and/or update the books.		Terminal Systems *Manage Transactions*	Terminal Systems *Deliver Hydrogen*
	Metered Amount Loaded	Metered Amount Loaded is the amount of hydrogen in Kg which has been loaded on the vehicle transport.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Manage Transactions*
	Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.			
Transport Driver to Terminal Operator Interactions	Load Authorization	Load Authorization is a signal used to activate the dispenser.		Terminal Systems *Manage Transactions*	Terminal Systems *Store & Transport Hydrogen*
	Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Deliver Hydrogen*
	Load Transaction Invoice / Billing Statement	The Load Transaction Invoice is issued by the producer and terminal operator upon receipt of hydrogen. This statement is used to complete a B2B transaction with the producer or terminal operations (if required as a part of an exchange arrangement) or used to update ledger information in the terminal operations which is reported up to the LCC and corporation to pay the producer and/or update the books.		Terminal Systems *Manage Transactions*	Terminal Systems *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
	Metered Amount Loaded	Metered Amount Loaded is the amount of hydrogen in Kg which has been loaded on the vehicle transport.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Manage Transactions*
	Metered Amount Unloaded	Metered Amount Unloaded is the amount of hydrogen which has been delivered either to the terminal or fuel station facility.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Manage Transactions*
	Request Delivery Conformance Report	Request Delivery Conformance Report is a mechanism for the Management Supply function to trigger the Maintain Compliance function to report out the latest compliance information for the entire system or individual system components.		Terminal Systems *Manage Supply*	Terminal Systems *Deliver Hydrogen*
	Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.		Terminal Systems *Manage Transactions*	Terminal Systems *Store & Transport Hydrogen*
	Unload Request	The Vehicle Transport Operator makes Unload Requests of the Terminal or Fuel Station Operator prior to the unload compressor being activated.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Deliver Hydrogen*
	Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Deliver Hydrogen*

Link	Systems Data Element			Data Source	Data Destination
Name	**Name**	**Description**	**Attributes**	**System and Function**	**System and Function**
		completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.			
Transport Driver to Terminal Unload Compressor Interactions	Metered Amount Unloaded	Metered Amount Unloaded is the amount of hydrogen which has been delivered either to the terminal or fuel station facility.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Manage Transactions*
	Unload Request	The Vehicle Transport Operator makes Unload Requests of the Terminal or Fuel Station Operator prior to the unload compressor being activated.		Terminal Systems *Store & Transport Hydrogen*	Terminal Systems *Deliver Hydrogen*
	Unload Transaction Invoice / Billing Statement	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.		Terminal Systems *Manage Transactions*	Terminal Systems *Store & Transport Hydrogen*

Table 28. Summary Systems / Services Data Exchange Matrix (SV-6) Associated Element Definitions

Element	Definition
Component	
Compliance Systems	
Corporate Systems	Corporate Systems is a collection of Information Systems which are a part of the corporate enterprise which support the functional organization.
Delivery Management System (Logistics Command Center)	The Delivery Management System is responsible for automating the management of the hydrogen supply, conformance to hydrogen fuel standards and maintenance of the Hydrogen Delivery System.
Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.
Function	
Deliver Hydrogen	Performs the Delivery Hydrogen Energy mission.
Manage Deliveries / Pickups / Flow Rates	Schedules and manages hydrogen deliveries and delivery requests
Manage Program	
Manage Supply	Manage Supply function is responsible for the flow of hydrogen through the Hydrogen Delivery System.
Manage Transactions	Manages all delivery transactions. Monitors and reports all completed delivery and sales transactions.
Monitor Hydrogen Location and Amount	Monitors hydrogen supply via reports from vehicle transports.
Monitor Supply Status	Monitors and reports the supply of hydrogen in the system.
Perform Conformance Testing	Performs all testing for compliance, conformance.
Remediate Non-conformance	Remediates all non-conforming systems.

Element	Definition
Store & Transport Hydrogen	The Store & Transport Hydrogen function is responsible for the transport and storage of hydrogen across the Hydrogen Delivery System.
Item	
Completed Delivery Transaction Information	Completed Delivery Transaction Information consists of the metered amount of hydrogen delivered, location, on-site storage tank and time. This information is used by the system to update reports to finance and to manage the available supply on-hand. This information is also used in conjunction with tank sensor readings in order to understand hydrogen energy loss, which has both financial and operational significance.
Completed Point-of-Sale Information	Completed Point-of-Sale Information contains amount of hydrogen, price per Kg and total amount.
Consumer Demand Information	Consumer Demand Information is reported to the producer in order for the producer to meet current hydrogen consumption rates.
Credit Request	Request made by the consumer for credit pre-authorization required prior to dispenser activation.
Customer Receipt	Customer Receipt contains completed transaction information - amount of H2, price per Kg and total amount either paid in cash or charged to credit.
Delivery Conformance Report / Fill Tag	The Delivery Conformance Report is provided by the vehicle transport driver to the terminal or fuel station operator upon arrival. It contains the hydrogen purity levels and other relevant information (level of particulate counts, other gases). This information should match the information on the fill tag which is attached to the hookup connection / valve on the vehicle transport trailer.
Delivery Schedule / Confirmation	Delivery schedules are generated by the LCC based on known supply. These schedules are periodically provided to fuel station and terminal operators in order to anticipate delivery time (origination). .
Delivery Waypoints	Delivery waypoints are used by drivers in addition to the onboard position / location system to follow predetermined hydrogen pickup and delivery routes.
Dispatch Maintenance Personnel	Dispatch Maintenance Personnel is a message that captures and describes a problem, remediation actions required (in addition to specialized equipment required - if any), proposed repair times and assigns a priority to the problem. The priority is used by maintenance operations in order to schedule maintenance activities. This schedule is providing to the LCC and relevant system operators to manage around repairs which may cause operational impacts.
Dispatch Transport	Dispatch Transport is a trigger used to dispatch a vehicle transport to make a delivery.
Engineering Change Request	Contains details pertaining to system design updates, such as the description of the flaw, how it impacts operations, any steps taken to remediate or address the problem previously and recommended or requested changes that need to be made to the system. Minor design changes are required to address flaws which impact system triggers this request.

Element	Definition
Facilities Maintenance Request	Facilities Maintenance Requests are made when the condition of company-owned facilities or property affects the operation of the overall system.
GPS Signal	
H2 Delivery Price	The price of hydrogen delivered to be used to generate billing statements, invoices.
Hydrogen Supply Information Request	Request to the producer to provide information regarding available hydrogen supply on-hand (stored) and current operating capacity.
IT Support Request	IT Support Requests are made when company-owned Information Technology asset failure affects the overall operation of the system.
Load Authorization	Load Authorization is a signal used to activate the dispenser.
Load Request	The Vehicle Transport Operator makes Load Requests of the Producer or Terminal Operator prior to the load dispenser being activated.
Load Transaction Complete	Load Transaction Complete signals the completion of the load transaction to the Move Hydrogen function.
Load Transaction Invoice / Billing Statement	The Load Transaction Invoice is issued by the producer and terminal operator upon receipt of hydrogen. This statement is used to complete a B2B transaction with the producer or terminal operations (if required as a part of an exchange arrangement) or used to update ledger information in the terminal operations which is reported up to the LCC and corporation to pay the producer and/or update the books.
Location Information	Location Information contains absolute location information using a latitude and longitude coordinate system.
Maintenance Request	Request Maintenance requests maintenance for terminal or fuel station facilities which may or may not have been detected by the System Management and Control functions reporting to the LCC.
Maintenance Schedule / Confirmation	Maintenance required is used to communicate the repair action and location required and acts as a confirmation to the maintenance request.
Metered Amount Loaded	Metered Amount Loaded is the amount of hydrogen in Kg which has been loaded on the vehicle transport.
Metered Amount Unloaded	Metered Amount Unloaded is the amount of hydrogen which has been delivered either to the terminal or fuel station facility.
New Equipment Request	New Equipment Request is sent when new parts or equipment is required be made (manufacturing) or purchased (procurement) to support maintenance operations.
Operational Compliance / Audit Information	Information from internal audits is reported back to corporate operations.
Operational Performance Requirements	Operation Performance Parameters are key performance parameters and required performance ranges in order to maintain compliance.

Element	Definition
Payment Method Selection	Payment Method Selection is made by the customer at the fuel station pump / dispenser.
Position Broadcasts / Beacons	Position Broadcasts / Beacons are signals provided by external systems in order to locate vehicle transport and maintenance vehicles.
Pre-Authorization	Pre-Authorization is a message that is used to activate the dispenser. Pre-authorization may be granted by the financial institution if credit was selected or by the fuel station operator if cash was selected.
Producer Conformance Information	H2 Conformance Information is conformance information provided to ongoing compliance functions in order to ensure that all hydrogen being delivered or stored meets operational requirements.
Producer Fill Tag / Conformance Report	
Producer Supply Information	Producer Supply Information indicates the available supply of stored hydrogen at the production site and the rate at which hydrogen is being produced.
Program Management Status Report	
Quality Assurance Requirements	Quality Assurance Requirements is a message placeholder for all requirements placed on the system during operation which further constrain system operation.
Remediation Action Required	Remediation action required is an action required to remediate non-compliance or non-conformance with operational performance parameters. This could require a repair, recalibration or some other action such as hydrogen purification.
Repairs Made	Repairs made is a positive acknowledgement that the repairs that were scheduled were made, the time of repair and resulting downtime (if-any), repair action and affected systems.
Request Delivery Conformance Report	Request Delivery Conformance Report is a mechanism for the Management Supply function to trigger the Maintain Compliance function to report out the latest compliance information for the entire system or individual system components.
Required Compliance / Conformance Actions	Actions to remediate non-compliant system operation.
Set Pipeline Pressure	Set Pipeline Pressure sets the pressure on the pipeline controlling the flow of hydrogen through the pipeline distribution system.
Storage and Transport Location	
Supply Status Request	Supply Status Request is a mechanism used to trigger storage systems to report out supply information.
Unload Authorization	Unload Authorization is a signal used to activate the unload storage compressor.
Unload Request	The Vehicle Transport Operator makes Unload Requests of the Terminal or Fuel Station Operator prior to the unload compressor being activated.

Element	Definition
Unload Transaction Complete	Unload Transaction Complete signals the completion of the unload transaction and that the delivery action has been completed. At this point the vehicle will either need to make another delivery as scheduled, return to the terminal facility and / or may be dispatched at any time to make another delivery.
Unload Transaction Invoice / Billing Statement	The Unload Transaction Invoice is issued to the terminal and fuel station operators upon receipt of hydrogen. This statement is used to complete a B2B transactions (if required) with the terminal or fuel station operator and/or used to update ledger information in the terminal or fuel station operations which is reported up to the LCC and corporation to pay the terminal or fuel station (if required) and/or update the books.
Updated System Compliance Report	Updated System Compliance Report is sent to corporate operations.
Link	
CMS to LCC Link	
Corporate Intranet	Provides the LCC connectivity back to the corporate enterprise and Information Technology infrastructure.
Customer to Fuel Station Dispenser HMI	Provides the customer a Human-Machine Interface to the Dispenser in order to support dispensing of hydrogen and sales transactions.
Customer to Fuel Station Operator Interactions	Supports verbal communications that may occur between the Customer and the Fuel Station Operator.
Fuel Station Remote Access Link to LCC	The Fuel Station remote access link provides connectivity to the Wide Area Network connecting operational node elements.
GPS Broadcast Satellite Link	Provides the positioning signal required by the Position / Location System on the Vehicle Transport to determine and report a location.
Maintenance Remote Access Link to LCC	Provide Maintenance with Access to the LCC.
Pipeline to Fuel Station Interface (Step-Out Phase)	Provides a physical interface between the fuel station and the Pipeline Distribution System. (Step-Out Phase)
Producer Remote Access Link to LCC	Provides a trusted link between the producer and the LCC to support hydrogen demand / supply reporting and load transaction information.
Production to Terminal Storage Hookup (Step-Out Phase)	Connects the Hydrogen Production System, operating at the Terminal, to the Terminal Storage System. (Step-Out Phase)
Remote Access Communications Links	Provides communications links back to the LCC.

Element	Definition
Terminal Facility Remote Access Link to LCC	Provides Terminal Facility remote access to the LCC.
Terminal Storage to Pipeline Hookup (Step-Out Phase)	Provides a physical interface between the Terminal Storage System and the Pipeline Distribution System. (Step-Out Phase)
Transport Driver to Fuel Station Operator Interactions	Transport Driver to Fuel Station Link represents the Human-to Human voice communications between the Transport Driver and the Fuel Station Operator.
Transport Driver to Fuel Station Unload Compressor Interactions	Provides an interface between the Vehicle Transport Operator and the Fuel Station Unload Compressor.
Transport Driver to Producer Operator Interactions	Transport Driver to Producer Link represents the Human-to-Human communications between the Transport Driver and the Producer Operator.
Transport Driver to Production Dispenser Interactions	Provides the Vehicle Transport Driver with an HMI to the Production Load Dispenser.
Transport Driver to Terminal Dispenser Interactions	Provides the Vehicle Transport Driver with an HMI to the Terminal Load Dispenser.
Transport Driver to Terminal Operator Interactions	Supports verbal communications between the Vehicle Transport Operator and the Terminal Operator.
Transport Driver to Terminal Unload Compressor Interactions	Provides the Vehicle Transport Driver with an HMI to the Terminal Unload Compressor.
Transport Vehicle to Storage System Hookup	Provides a physical interface between the Vehicle Transport Storage and the Fuel Station Unload Compressor.
Transport Vehicle to Terminal Dispenser Hookup	Provides the Vehicle Transport Driver with an HMI to the Terminal Load Dispenser.
Transport Vehicle to Terminal Storage Hookup	Provides the Vehicle Transport with a physical interface to the Terminal Storage System.
Vehicle Transport to Producer Dispenser Hookup	Provides a physical interface between the Vehicle Transport Storage and the Production Load Dispenser
Wide Area Network (Financial Institution)	Provides a Wide Area Network connection from the Fuel Station LAN to the Financial Institution.

Appendix B.15: Systems Technology Forecast (SV-9)

Table 29. Systems Technology Forecast (SV-9)

Element	Technology Forecast	Time Frame	Technology Area
Component			
Forecourt Systems	Std.6.2 Gaseous Hydrogen - Service Stations (Working Group #11 / ISO TS 20100) http://www.fuelcellstandards.com/1.2.11.htm	Long-Term	Fuel Station
	Std.6.3 Refueling Station (European Integrated Hydrogen Project (EIHP) - Work Package 2) http://www.fuelcellstandards.com/3.3.htm	Long-Term	Fuel Station
Maintenance Systems	Std.11.4 Expert Watch Group on Fuels for Fuel Cells (CEN/TC19) http://www.fuelcellstandards.com/3.1.htm	Long-Term	Fuel Standards
	Std.12.1 Standard Test Method for Determination of Trace Contaminants in Hydrogen and Related Fuel Cell Feed Gases (ASTM WK4548) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.2 Standard Practice for Sampling of High Pressure Hydrogen and Related Fuel Cell Feed Gases (ASTM WK 5847) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.3 Standard Test Method for Ion Selective Electrode or Ion Chromatography Based Determination of Ammonia in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK6527) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.4 Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK6624)	Long-Term	Test & Measurement

Element	Technology Forecast	Time Frame	Technology Area
	http://www.fuelcellstandards.com/2.3.htm		
	Std.12.5 Standard Test Method for Determination of Ammonia in Hydrogen and Other Fuel Cell Feed Gases by Gas Chromatography and Nitrogen Chemiluminescence Detection (ASTM WK8150) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.6 Standard Test Method for Ion Chromatography Based Determination of Cations in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK9211) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.7 Standard Test Method for Determination and Sampling of Particulate Matter in High Pressure Hydrogen Used as a Gaseous Fuel with an In-Stream Filter (ASTM WK9688) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.8 Standard Test Method for Determination of Ammonia and Trace Water in Hydrogen and Other Fuel Cell Gaseous Fuels by Infrared Spectroscopy (ASTM WK10196) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.9 Standard Test Method for Determination of Trace Hydrogen Sulfide, Methyl Mercaptan and Carbonyl Sulfide in Hydrogen Fuel (ASTM WK18779) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
Function			
2 Maintain Compliance	Std.11.4 Expert Watch Group on Fuels for Fuel Cells (CEN/TC19) http://www.fuelcellstandards.com/3.1.htm	Long-Term	Fuel Standards
	Std.12.1 Standard Test Method for Determination of Trace Contaminants in Hydrogen and Related Fuel Cell Feed Gases (ASTM WK4548)	Long-Term	Test & Measurement

Element	Technology Forecast	Time Frame	Technology Area
	http://www.fuelcellstandards.com/2.3.htm		
	Std.12.2 Standard Practice for Sampling of High Pressure Hydrogen and Related Fuel Cell Feed Gases (ASTM WK 5847) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.3 Standard Test Method for Ion Selective Electrode or Ion Chromatography Based Determination of Ammonia in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK6527) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.4 Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK6624) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.5 Standard Test Method for Determination of Ammonia in Hydrogen and Other Fuel Cell Feed Gases by Gas Chromatography and Nitrogen Chemiluminescence Detection (ASTM WK8150) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.6 Standard Test Method for Ion Chromatography Based Determination of Cations in Hydrogen and Other Fuel Cell Feed Gases (ASTM WK9211) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.7 Standard Test Method for Determination and Sampling of Particulate Matter in High Pressure Hydrogen Used as a Gaseous Fuel with an In-Stream Filter (ASTM WK9688) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement
	Std.12.8 Standard Test Method for Determination of Ammonia and Trace Water in Hydrogen and Other Fuel Cell Gaseous Fuels by Infrared Spectroscopy (ASTM	Long-Term	Test & Measurement

Element	Technology Forecast	Time Frame	Technology Area
	WK10196) http://www.fuelcellstandards.com/2.3.htm		
	Std.12.9 Standard Test Method for Determination of Trace Hydrogen Sulfide, Methyl Mercaptan and Carbonyl Sulfide in Hydrogen Fuel (ASTM WK18779) http://www.fuelcellstandards.com/2.3.htm	Long-Term	Test & Measurement

Appendix B.16: Technology Standards Profile & Forecast (TV-1/TV-2)

Table 30. Technology Standards Profile & Forecast (TV-1/TV-2)

Element	Standard	Time Frame	Source
Component			
Forecourt Systems	Std.1.1 Hydrogen Fueling Station Codes and Standards (DOE) http://www.fuelcellstandards.com/hydrogenfuelingstation.htm	Current	Std.1 Safety / General Design
	Std.1.3 Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks: Chapter 10 Gaseous Hydrogen Systems (NFPA 55) http://www.fuelcellstandards.com/2.1.6.1.htm	Current	Std.1 Safety / General Design
	Std.6.1 Airport Hydrogen Fuelling Facility Operation (ISO/PAS 15594) http://www.fuelcellstandards.com/1.2.4.htm	Current	
Maintenance Systems	Std.1.1 Hydrogen Fueling Station Codes and Standards (DOE) http://www.fuelcellstandards.com/hydrogenfuelingstation.htm	Current	Std.1 Safety / General Design
	Std.1.3 Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks: Chapter 10 Gaseous Hydrogen Systems (NFPA 55) http://www.fuelcellstandards.com/2.1.6.1.htm	Current	Std.1 Safety / General Design
	Std.1.4 Canadian Hydrogen Installation Code (CAN/BNQ 1784) http://www.fuelcellstandards.com/2.2.htm	Current	Std.1 Safety / General Design

Element	Standard	Time Frame	Source
	Std.3.1 Standard Test Method for Electronic Measurement for Hydrogen Embrittlement from Cadmium-Electroplating Processes (ASTM F326-96 / WK10222) http://www.fuelcellstandards.com/2.3.2.htm	Current	Std.3 Embrittlement Tests
	Std.3.2 Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating Processes and Service Environments (ASTM F519-08) http://www.fuelcellstandards.com/2.3.2.htm	Current	Std.3 Embrittlement Tests
	Std.3.3 Standard Test Method for Electrochemical Measurement of Diffusible Hydrogen in Steel (ASTM F1113-87 / WK 6483) http://www.fuelcellstandards.com/2.3.2.htm	Current	Std.3 Embrittlement Tests
	Std.3.4 Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (ASTM F1459-06) http://www.fuelcellstandards.com/2.3.2.htm	Current	Std.3 Embrittlement Tests
	Std.3.5 Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique (ASTM F1624-06) http://www.fuelcellstandards.com/2.3.2.htm	Current	Std.3 Embrittlement Tests
	Std.3.6 Standard Terminology Relating to Hydrogen Embrittlement (ASTM F2078-01 / WK12962) http://www.fuelcellstandards.com/2.3.2.htm	Current	Std.3 Embrittlement Tests
	Std.11.1 Commodity Specification for Hydrogen (CGA Publication G5.3) http://www.fuelcellstandards.com/2.1.2.2.htm	Current	Std.11 Fuel Standards
	Std.11.2 Hydrogen Fuel - Product Specification, Part 2: PEM fuel cell applications for road vehicles (ISO/TS 14687-2) http://www.fuelcellstandards.com/1.2.12.htm	Current	Std.11 Fuel Standards

Element	Standard	Time Frame	Source
	Std.11.3 Hydrogen Quality Guideline for Fuel Cell Vehicles (SAE J2719) http://www.fuelcellstandards.com/2.1.7.2.htm	Current	Std.11 Fuel Standards
Terminal Systems	Std.1.3 Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks: Chapter 10 Gaseous Hydrogen Systems (NFPA 55) http://www.fuelcellstandards.com/2.1.6.1.htm	Current	Std.1 Safety / General Design
Vehicle Transport Systems	Std.1.3 Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks: Chapter 10 Gaseous Hydrogen Systems (NFPA 55) http://www.fuelcellstandards.com/2.1.6.1.htm	Current	Std.1 Safety / General Design
Function			
2 Maintain Compliance	Std.11.1 Commodity Specification for Hydrogen (CGA Publication G5.3) http://www.fuelcellstandards.com/2.1.2.2.htm	Current	Std.11 Fuel Standards
	Std.11.2 Hydrogen Fuel - Product Specification, Part 2: PEM fuel cell applications for road vehicles (ISO/TS 14687-2) http://www.fuelcellstandards.com/1.2.12.htm	Current	Std.11 Fuel Standards
	Std.11.3 Hydrogen Quality Guideline for Fuel Cell Vehicles (SAE J2719) http://www.fuelcellstandards.com/2.1.7.2.htm	Current	Std.11 Fuel Standards

Table 31. Technology Standards Profile & Forecast (TV-1/TV-2) Associated Element Definitions

Element	Definition
Component	
Forecourt Systems	Forecourt Systems are systems which reside at the Fuel Station. Forecourt Systems include On-site storage, unload compressor, pump dispenser, fuel station operator and fuel station office (fuel station operator, ledger, point-of-sale workstation with human-machine interface)
Maintenance Systems	Compliance systems are used by systems maintainers in order to measure the system operational performance. This information is used by the maintainer to make repairs to the system or remediate non-conformation to operational requirements.
Terminal Systems	Terminal Systems reside at the Terminal facility. Terminal systems consist of on-site storage tanks, unload compressors, load dispensers, terminal operations (terminal operators, ledger, workstation HMI).
Vehicle Transport Systems	Vehicle transport systems consist of the vehicle, trailer, storage tubes and a management component used to transport hydrogen in the delivery system.
Function	
Maintain Compliance	The Maintain Compliance function is responsible for setting performance thresholds for operational components, testing and measuring the system components against those thresholds and performing tasks to remediate any non-compliance, non-conforming equipment or hydrogen product.
Standard	
Std.1 Safety / General Design	This section contains codes and standards which apply to safety and the general design of hydrogen systems.
Std.1.1 Hydrogen Fueling Station Codes and Standards (DOE)	http://www.fuelcellstandards.com/hydrogenfuelingstation.htm
Std.1.3 Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks: Chapter 10 Gaseous Hydrogen Systems (NFPA 55)	http://www.fuelcellstandards.com/2.1.6.1.htm
Std.1.4 Canadian Hydrogen Installation Code (CAN/BNQ 1784)	http://www.fuelcellstandards.com/2.2.htm
Std.3 Embrittlement Tests	Standards for testing material for hydrogen embrittlement.
Std.3.1 Standard Test Method for Electronic Measurement for Hydrogen Embrittlement from Cadmium-Electroplating Processes (ASTM F326-96 / WK10222)	http://www.fuelcellstandards.com/2.3.2.htm
Std.3.2 Standard Test Method for Mechanical	http://www.fuelcellstandards.com/2.3.2.htm

Element	Definition
Hydrogen Embrittlement Evaluation of Plating Processes and Service Environments (ASTM F519-08)	
Std.3.3 Standard Test Method for Electrochemical Measurement of Diffusible Hydrogen in Steel (ASTM F1113-87 / WK 6483)	http://www.fuelcellstandards.com/2.3.2.htm
Std.3.4 Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (ASTM F1459-06)	http://www.fuelcellstandards.com/2.3.2.htm
Std.3.5 Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique (ASTM F1624-06)	http://www.fuelcellstandards.com/2.3.2.htm
Std.3.6 Standard Terminology Relating to Hydrogen Embrittlement (ASTM F2078-01 / WK12962)	http://www.fuelcellstandards.com/2.3.2.htm
Std.6.1 Airport Hydrogen Fuelling Facility Operation (ISO/PAS 15594)	http://www.fuelcellstandards.com/1.2.4.htm
Std.11 Fuel Standards	Standards relating to hydrogen energy.
Std.11.1 Commodity Specification for Hydrogen (CGA Publication G5.3)	http://www.fuelcellstandards.com/2.1.2.2.htm
Std.11.2 Hydrogen Fuel - Product Specification, Part 2: PEM fuel cell applications for road vehicles (ISO/TS 14687-2)	http://www.fuelcellstandards.com/1.2.12.htm
Std.11.3 Hydrogen Quality Guideline for Fuel Cell Vehicles (SAE J2719)	http://www.fuelcellstandards.com/2.1.7.2.htm

Appendix C: Station Location Analysis

Formulation

Input Variables:

F = fixed costs of converting a station (estimated value provided by system architecture, H2A). [8] This also includes the NPV of any fixed operating costs.

P = capacity limit of a station (estimated value provided by system architecture, H2A)

D_i = demand within a zip code (estimate a Poisson arrival interval, based on the vehicle population, average miles consumed, and a similar refueling interval (~300 miles)

γ_{ij} = accessibility matrix (0 or 1) to indicate which ***i*** zip codes are accessible to supply demand from other ***j*** zip codes.

φ = Profit factor per kg of H2 demanded, to be applied in the γ_{ij} matrix.

C_{jk} = cost matrix (0 or 1) to indicate how many ***k*** stations are available to provide the supply in zip code ***j.***

Decision Variables (outputs):

X_{ij} = amount of fuel (kg) supplied to customers living in zip code ***i*** from zip code ***j***.

X_{jk} = amount of fuel (kg) supplied by ***k*** stations in zip code ***j***.

Objective Function:

The Objective is to maximize profit. However, to keep the form of a min cost network that forms the basis for the model, our objective is a minimum cost network flow, therefore we are adding negative cost terms for profits. The base form of the min cost objective function for network analysis is:

Min cost $z = \sum [c_{ij} \cdot x_{ij}]$

However, there are different "pieces" of the network which have different costs and capacities. Therefore, a more accurate formulation for this problem is:

Min cost = sum { negative profit earned * flow for accessible stations}

+ sum { Fixed cost per station * any arc carrying flow (i.e., station providing service) }

Our objective function will then be of the form:

Min cost

$$z = -(\cdot \Sigma_{\downarrow}\blacksquare(i \in N1 @ j \in N2)\,[\gamma_{\downarrow}ij \cdot x_{\downarrow}ij\,] + F \cdot \Sigma_{\downarrow}\blacksquare(j \in N2 @ k \in N3)\,[c_{\downarrow}jk \cdot x_{\downarrow}jk\,]$$

Constraints:

$X_{ijk} >= 0$

$x_{ik} \leq P \text{ for all } i,j \in A$; *{supply constraint; stations supply can't exceed capacity P}*

$x_{ij} \geq D_j$ *{demand constraint; demand must be satisfied}*

$x_{jk} \geq 0.5P \text{ for } i,j \in A \text{ (all non-zero arcs)}$; *{lower bound – don't build a station without 50% capacity used}*

$x_{ij} - x_{jk} = 0$; for each ***j*** {flow balance}

[8] Leveraged cost data from H2A Component Model, H2A Scenario Model, developed and maintained by the DOE @ http://www.hydrogen.energy.gov/h2a_delivery.html

C2 – MPL Model Code

```
{H2 annual analysis}

TITLE
      H2_annual;

INDEX
      i = 1..42;
      j = 1..42;
      k = 1..10;

DATA
      Cij[i,j] := DATAFILE ("cij5.csv"); !possible covers (0,1)
      Di[i,k] := DATAFILE ("dik.hi.csv");  !kg/mo required
      OpCost := 1.63; ! this is fixed, assuming learning curve offsets inflation
      p[k] := (7.956, 8.194, 8.440, 8.693, 8.954, 9.223, 9.500, 9.785, 10.078,
      10.380); !low
      p[k] := (9.102, 9.557, 10.035, 10.537, 11.064, 11.617, 12.198, 12.808,
      13.448, 14.120); !med
      p[k] := (10.387, 11.115, 11.893, 12.725, 13.616, 14.569, 15.589, 16.680,
      17.847, 19.097); !hi
      Capital := 934575;      ! Amortized Capital station cost (2015$)
      FC := 827435;     !Annual fixed cost (2015$)
      F := Capital + FC; !amortized capital + FC
      U := 1500; !1500kg daily output
      r[k] := (0.9434, 0.8900, 0.8396, 0.7921, 0.7473, 0.7050, 0.6651, 0.6274,
      0.5919, 0.5584)


BINARY VARIABLES
      Cover[i,j] -> Y;

INTEGER VARIABLES
      Stations[j,k] -> X;

MACRO
      Revenue := SUM(k: (SUM(j: SUM(i:
      (Di[i,k]*Cij[i,j]*Cover[i,j]*p[k]*12*r[k])))));
      CapCost := SUM(k: (SUM(j: Stations[j,k]*F*r[k])));
      VarCost := SUM(k: SUM(i: (Di[i,k]*12*OpCost)));

MODEL
      MAX Profit = Revenue - CapCost - VarCost;

SUBJECT TO
      Coverage[i,j] -> CV: SUM(j: Cover[i,j]) = 1;
      Capacity[j,k] -> CP: SUM(i: Di[i,k]*Cij[i,j]*Cover[i,j]) <=
      (Stations[j,k]*22*U);
!     StationExist[i,j,k] -> SX: Stations[j,k] >= Cij[i,j]*Cover[i,j];

BOUNDS
      Stations[j,k] >= 0;
END
```

Results

	a	c	o	p	q	r	s	t	u	v	w	x
Price (hi, med, lo)	lo	med	hi	med	med	lo	lo	hi	lo	hi	hi	lo
Demand (hi, med, lo)	med	med	hi	med	med	lo	lo	hi	med	med	hi	lo
OpCost	1.63	1.63	3.21	3.21	0.60	0.60	1.63	1.63	1.63	1.63	0.60	3.21
Objective Function (profit)	(14,548)	13,283	188,019	(23,790)	37,451	(1,553)	(18,602)	298,658	(14,548)	51,751	370,783	(44,755)
Revenue	83,834	126,661	678,936	126,661	126,661	44,893	44,893	678,936	83,834	188,327	678,936	44,893
Cap Cost	60,137	75,132	266,138	75,132	75,132	36,514	36,514	266,138	60,137	98,331	266,138	36,514
Var Cost	38,246	38,246	224,779	75,318	14,078	9,932	26,981	114,140	38,246	38,246	42,015	53,134
Year	# Stat	# Stat	# Stat	# Stat	# Stat	# Stat	# Stat	# Stat	# Stat	# Stat	# Stat	# Stat
1	3	4	11	4	4	2	2	11	3	6	11	2
2	3	4	11	4	4	2	2	11	3	6	11	2
3	3	4	11	4	4	2	2	11	3	6	11	2
4	3	4	11	4	4	2	2	11	3	6	11	2
5	3	4	11	4	4	2	2	11	3	6	11	2
6	5	6	13	6	6	2	2	13	5	6	13	2
7	5	6	19	6	6	4	4	19	5	6	19	4
8	6	7	30	7	7	4	4	30	6	10	30	4
9	8	10	46	10	10	4	4	46	8	12	46	4
10	11	13	66	13	13	6	6	66	11	16	66	6

Table 32. NPV Results

Table 33. NPV Scenarios (Location Analysis)

	Scen #1	Scen #2	Scen #3	Scen #4	Scen #5	Scen #6	Scen #7	Scen #8	Scen #9	Scen #10	Scen #11	Scen #12	
Price	lo	lo	lo	lo	lo	med	med	med	hi	hi	hi	hi	
Demand	lo	lo	lo	med	med	med	med	med	med	hi	hi	hi	
Op Cost	0.60	1.63	3.21	1.63	1.63	0.60	1.63	3.21	1.63	0.60	1.63	3.21	
Zip Code													**Total**
20120									3	11	11	11	**11**
20170	3	3	3	4	4	4	4	4	3	7	7	7	**7**
20194										4	4	4	**4**
22030				3	3	3	3	3	3	7	7	7	**7**
22039										6	6	6	**6**
22042										2	2	2	**2**
22044										7	7	7	**7**
22066									2	4	4	4	**4**
22124										4	4	4	**4**
22151						2	2	2					**0**
22152										4	4	4	**4**
22181									2				**0**
22307	3	3	3						3	10	10	10	**10**
22308				4	4	4	4	4					**0**
Total	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**3**	**11**	**11**	**11**	**11**

Table 34. Max Number of Stations (Location Analysis)

Scenario	(All)

Max of # Stations	1	2	3	4	5	6	7	8	9	10	Grand Total
1	1	1	1	1	1	2	3	5	7	11	11
5	1	1	1	1	1	2	2	3	5	7	7
9	1	1	1	1	1	1	1	2	3	4	4
13	1	1	1	1	1	1	2	3	5	7	7
17	1	1	1	1	1	1	2	3	4	6	6
19	1	1	1	1	1	1	1	1	2	2	2
21	1	1	1	1	1	1	2	3	5	7	7
23	1	1	1	1	1	1	1	2	3	4	4
27	1	1	1	1	1	1	1	2	3	4	4
29	1	1	1	1	1	1	1	1	2	2	2
30	1	1	1	1	1	1	1	2	3	4	4
33	1	1	1	1	1	1	1	1	2	2	2
37	1	1	1	1	1	2	3	4	6	10	10
38	1	1	1	1	1	2	2	2	3	4	4
Grand Total	**1**	**1**	**1**	**1**	**1**	**2**	**3**	**5**	**7**	**11**	**11**

Appendix C.1: Station Cost Analysis (Assumptions and Fixed Costs)

Table 35. Station Cost Analysis

Terminal: Economic Assumptions		
		Comments
Start-up year	2010	This start-up year represents a near term case
Real After-tax Discount Rate (%)	2.8%	LIBOR
Analysis period (years)	20	This is the base analysis period of H2A cases.
Compressor Lifetime (years)	20	
Storage Lifetime (years)	20	
Terminal Lifetime (years)	20	
Inflation (%)	2.8%	LIBOR
State Taxes (%)	5.0%	VA State Tax
Federal Taxes (%)	35.0%	Corporate Tax Bracket - H2A standard
Total Tax Rate (%)	40.0%	

Terminal: Capital Investment - Equipment Costs			
Major Pieces/Systems of Equipment	Number	Calculated Installed Cost	
Number of Stations	1		
Truck Loading Compressor			
Number of Units	1	$324,526	$324,526
Storage Compressor			
Number of Units	2	$484,169	$484,169
Compressed Gas H2 Storage			
Number of Units	4	$403,230	$403,230
Buildings and structures	1	$50,000	$50,000
Truck Scale	1	$80,000	$80,000
CAPITAL INVESTMENT $2010 / STATION EQUIPMENT	$1,341,925		
TOTAL CAPITAL INVESTMENT $2010			$1,341,925

Terminal: Capital Investment			
	Base Case:		Comments:
Land Costs			
Terminal Width (m)	40		
Number of Stacks of Cylinders	4		
Number of Rows of Cylinder Stacks	2		Based on assumption that each row of storage cylinders is no wider than the width of terminal bays
Terminal Length (m)	25		
GH2 Terminal Land Required (m2)	1,000		
Land Cost ($2010/m2)	$267.28		
Total Land Cost $2010	$267,280		
Other Capital Costs			
Site Preparation (% of Initial Capital Investment)	4.0%		
Engineering & Design (% of Initial Capital Investment)	10.0%		
Project Contingency (% of Initial Capital Investment)	10.0%		
Up-Front Permitting Costs (% of Initial Capital Investment)	3.0%		
Owner's Costs (% of Initial Capital Investment)	12.0%		
Site Preparation $2010	$10,691		
Engineering & design $2010	$26,728		
Project contingency $2010	$26,728		
Up-Front Permitting Costs $2010	$8,018		
Owner's Costs $2010	$32,074		
CAPITAL INVESTMENT $2010 / STATION	$371,519		
TOTAL CAPITAL INVESTMENT STATIONS$2010	1	$371,519	

Appendix C.2: Station Cost Analysis (Variable Costs)

Table 36. Station Cost Analysis (Variable Costs)

Terminal: O&M Costs			
	Base Case:		Comments
Labor Cost			
Labor required (hrs/year)	13,140		Base case is 2 operators, 18 hours a day, 7 days a week for a 100,000 kg/day average capacity facility. Scaling factor of 0.25 is used for other sized facilities.
Labor cost $2010/man-hr)	$28.20		
TOTAL LABOR COST $2010/year	$370,548		
Electricity Cost			
Storage Compressor Electricity Consumption (kWh)	1,233,886		
Truck Loading Compressor Electricity Consumption (kWh)	1,283,393		
Electricity Cost $2010/kWh)	$0.053		
Total Electricity Cost $2010/year)	$134,537.85		
Insurance (% of Total Capital Investment)	1.0%		
Insurance $2010/year)	$17,134		
Property Taxes (% of Total Capital Investment)	1.5%		
Property Taxes $2010/year)	$25,702		
Licensing and Permits (% of Total Capital Investment)	1.0%		
Licensing and permits $2010/year)	$17,134		
Operating, Maintenance and Repairs for Compressor (% of Compressor Total Capital Investment)	4.0%		
Operating, Maintenance and Repairs for Remainder of Facility (% of Total Capital Investment for Remainder of Facility)	0.5%		
Operating, Maintenance and Repairs ($2010/year)	$77,105		
Overhead and G&A (% of Total Labor Cost)	50.0%		
Overhead and G&A $2010/year)	$185,274		
Misc. Fixed Operating Costs $2010/year)	$0		
TOTAL O&M COSTS ($/year)	$827,435		

Appendix C.3: Tanker Cost Analysis (Assumptions, Fixed, and Variable Costs)

Table 37. Tanker Cost Analysis (Assumptions, Fixed and Variable Costs)

Tanker: Economic Assumptions		
	Base Case	Comments
Start-up year	2010	
Real After-tax Discount Rate (%)	2.8%	LIBOR
Analysis period (years)	20	This is the base analysis period of H2A cases.
Tractor Lifetime (years)	5	
Trailer Lifetime (years)	20	
Inflation (%)	2.8%	LIBOR
State Taxes (%)	5.0%	VA State Tax
Federal Taxes (%)	35.0%	Corporate Tax Bracket - H2A standard
Total Tax Rate (%)	40.0%	

Tanker: Capital Investment - Equipment Costs			
Major Pieces/Systems of Equipment	Unit Cost $2010	Number of Units	Total Cost $2010
Tractor (per unit)	$75,000	1	$75,000
Tube Tank Trailer (per unit)	$225,000	1	$225,000
Loading/Unloading Equipment	$15,000	1	$15,000
Total Capital Investment	$315,000	$315,000	

Tanker: O&M Costs		
	Cost	Comments
Labor Cost		
Labor required (man-hours/year/tractor)	3,744	
Labor cost $2010	$31.00	Heavy duty truck operator with some offloading capabilities. This value is unburdened labor cost.
TOTAL LABOR COST $2010/year	$116,064	
Fuel Consumption (gallons/trip)	26.7	
TOTAL FUEL COST $2010/year	$16,640	
Insurance rate $2010/year	$0.102	Assuming $0.051 per mile, which is doubled to $0.102 per mile for hazardous cargo, American Trucking Assn.
Insurance $2010/year	$15,300	
Licensing and permits rate $2010/year	$0.056	Assuming $0.056 per mile, which is doubled to $0.112 per mile for hazardous cargo, 50% of this value is allocated to tractor. American Trucking Assn.
Licensing and permits $2010/year	$8,400	
Operating, Maintenance and Repairs Rate $2010/year	$0.047	Outside maintenance and repairs =$0.028/mile. Add $0.019/mile for tires. American Trucking Assn.
Operating, Maintenance and Repairs $2010/year	$7,050	
Overhead and G&A (% of total labor cost)	20.0%	
Overhead and G&A $2010/year	$23,213	
Total O&M Costs ($/year)	$186,667	

Appendix C.4: Expected H2 Adoption Scenarios

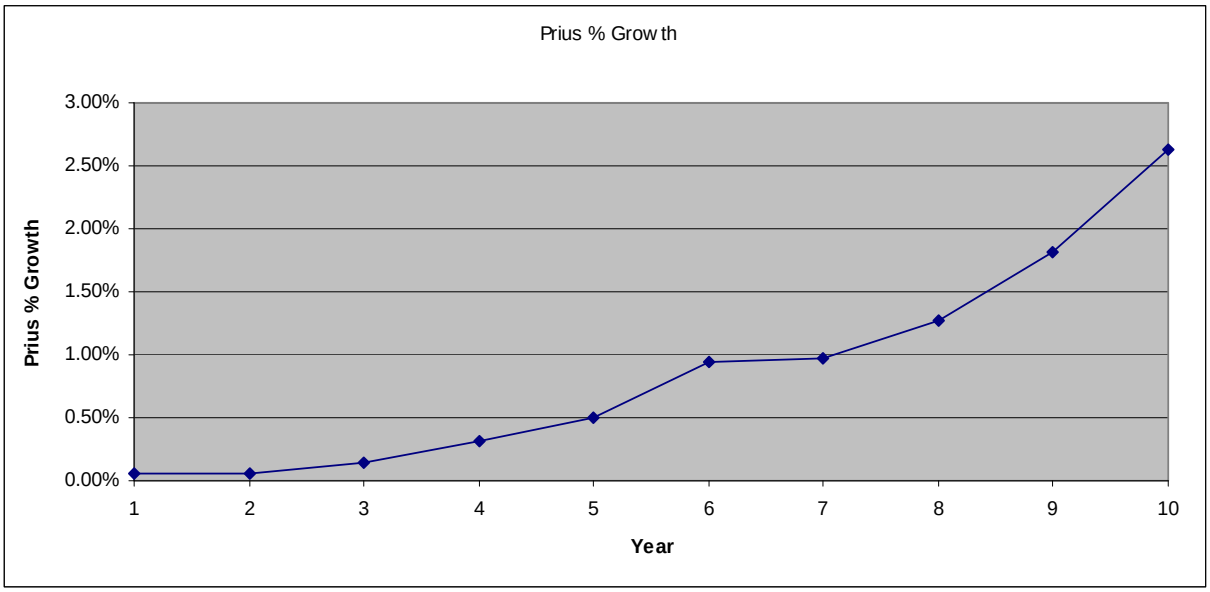

Figure 65. Prius Percent Growth in Sales

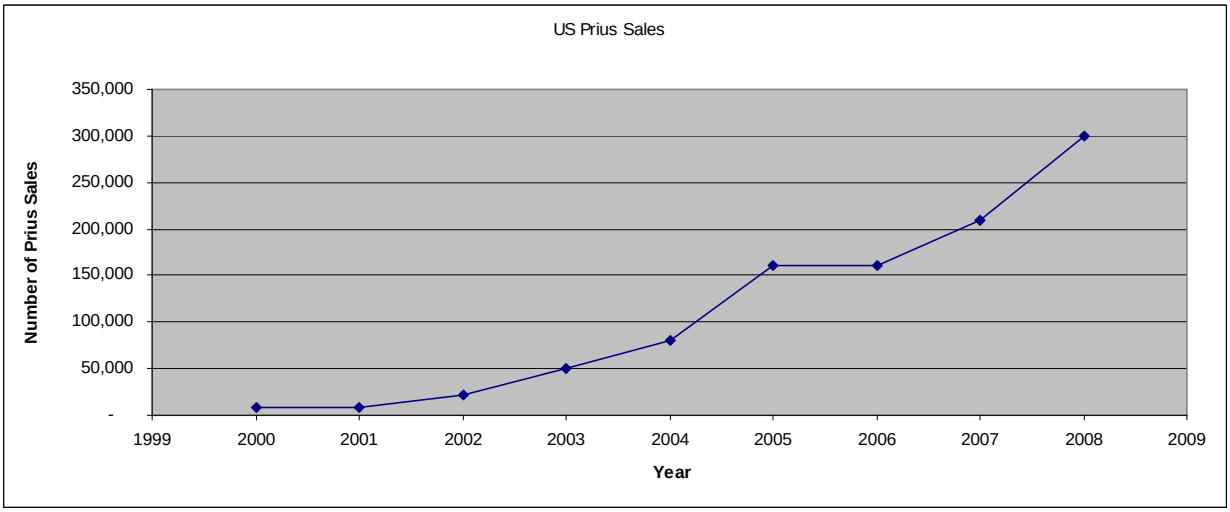

Figure 66. Prius Annual Sales

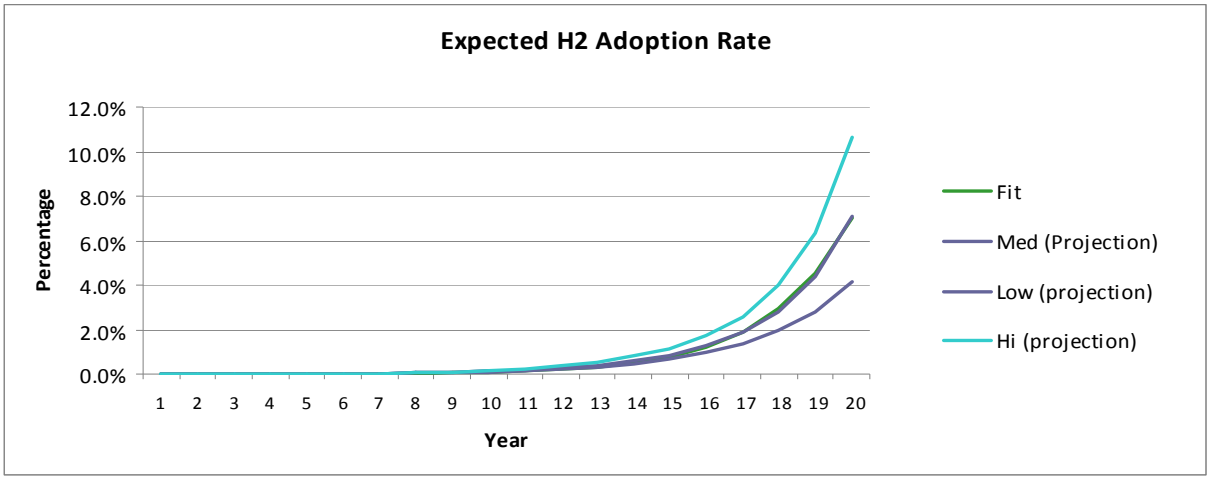

Figure 67. Expected H2 Adoption Scenarios

Appendix C.5: Tree Diagram

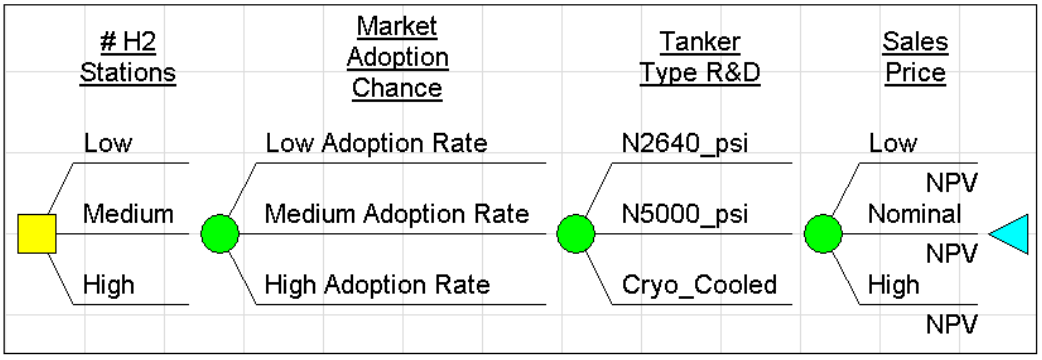

Figure 68. Tree Diagram

Appendix C.6: Net Present Value Under Multiple Scenarios

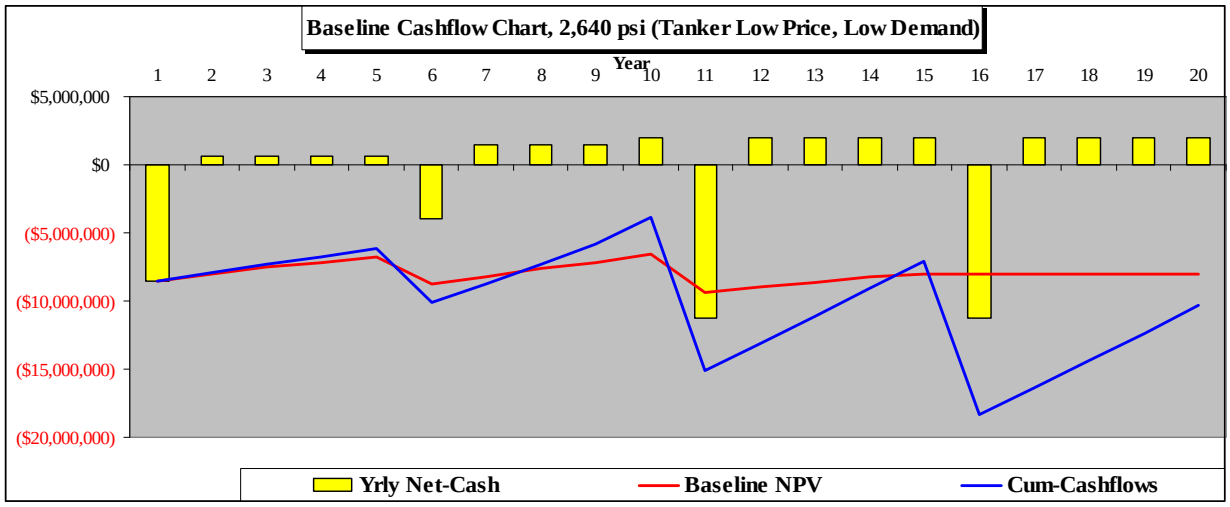

Figure 69. NPV and Cumulative Cash Flow (2640 psi Tanker, Low Price, Low Demand)

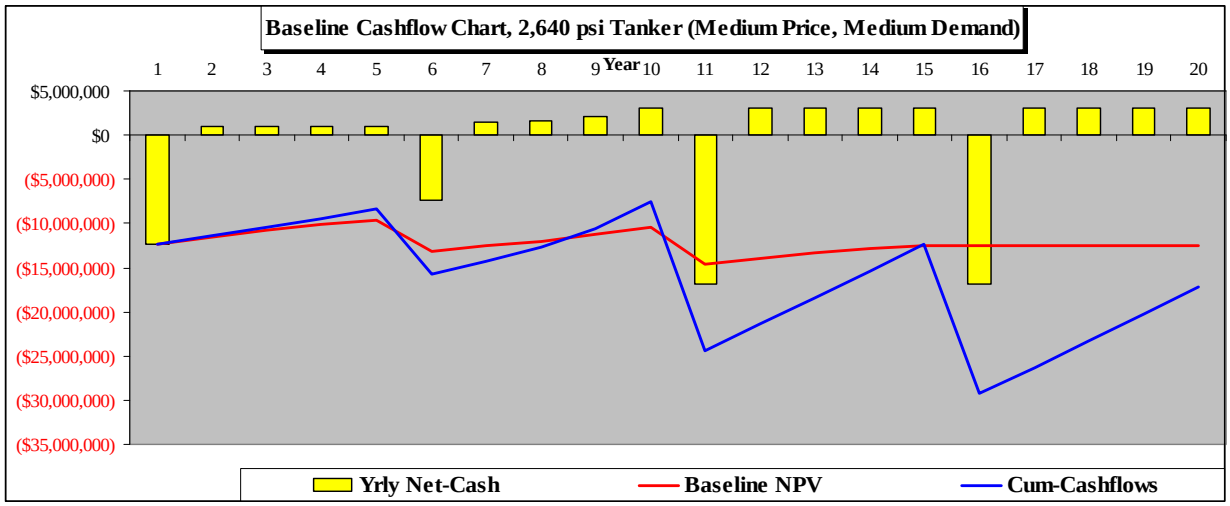

Figure 70. NPV and Cumulative Cash Flow (2640 psi Tanker, Medium Price, Medium Demand)

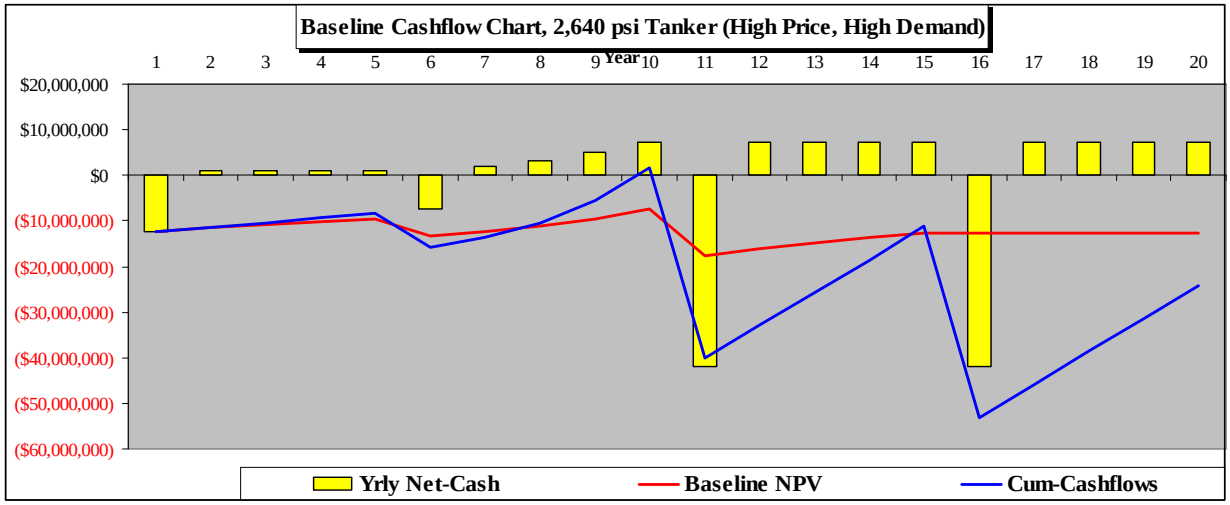

Figure 71. NPV and Cumulative Cash Flow (2640 psi Tanker, High Price, High Demand)

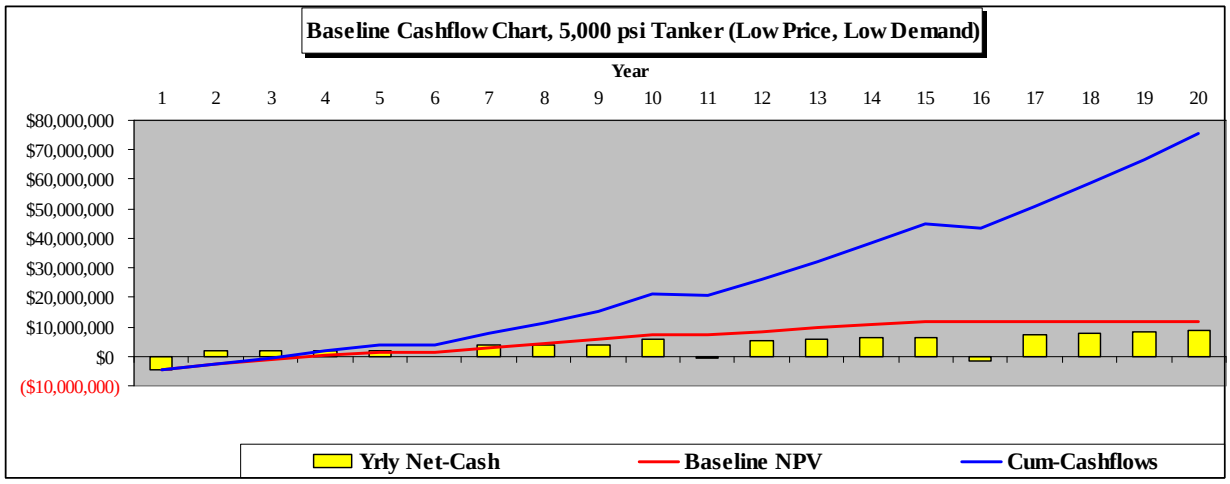

Figure 72. NPV and Cumulative Cash Flow (5000 psi Tanker, Low Price, Low Demand)

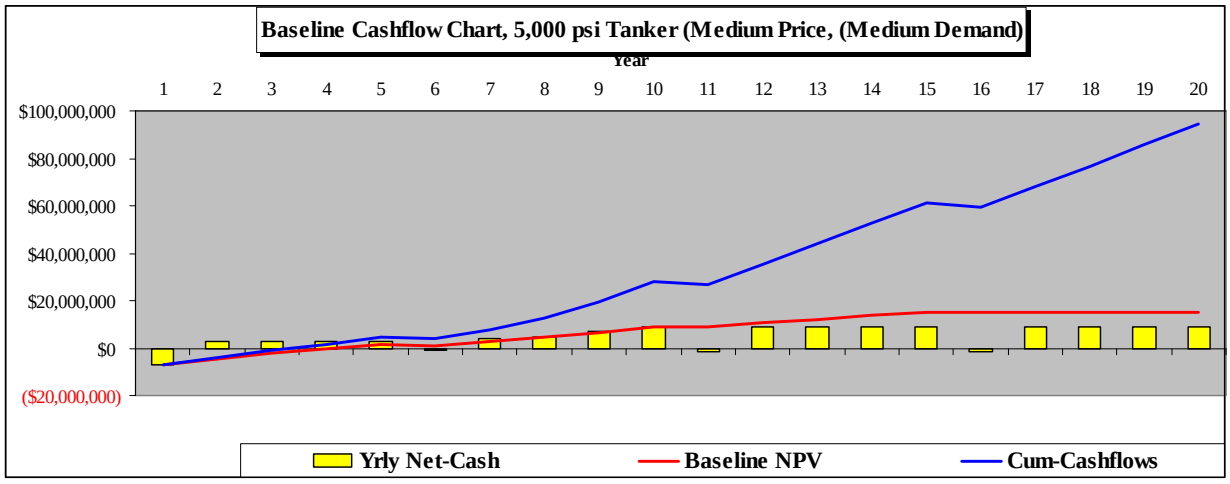

Figure 73. NPV and Cumulative Cash Flow (5000 psi Tanker, Medium Price, Medium Demand)

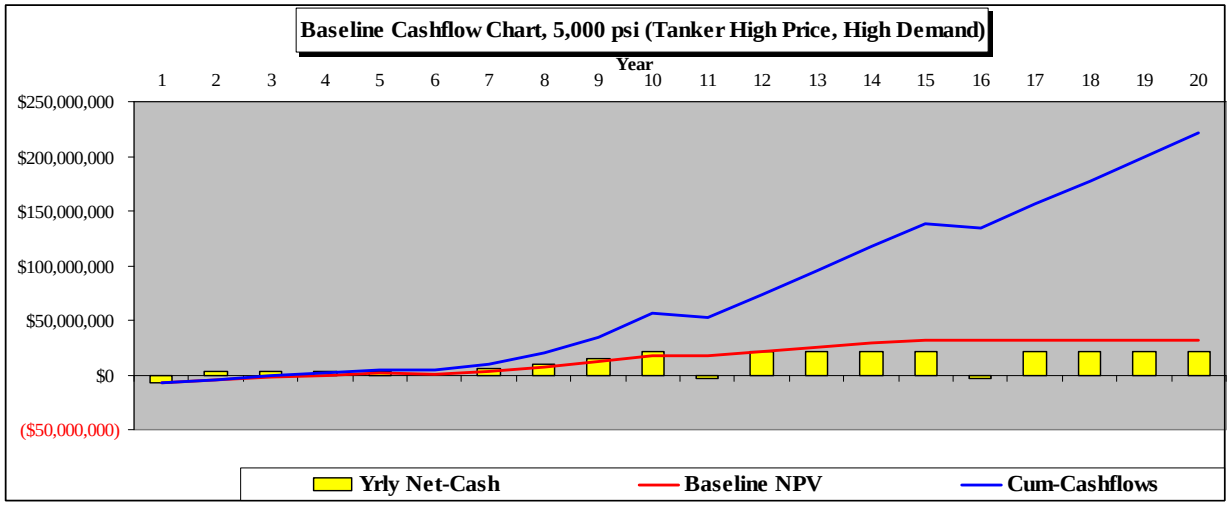

Figure 74. NPV and Cumulative Cash Flow (5000 psi Tanker, High Price, High Demand)

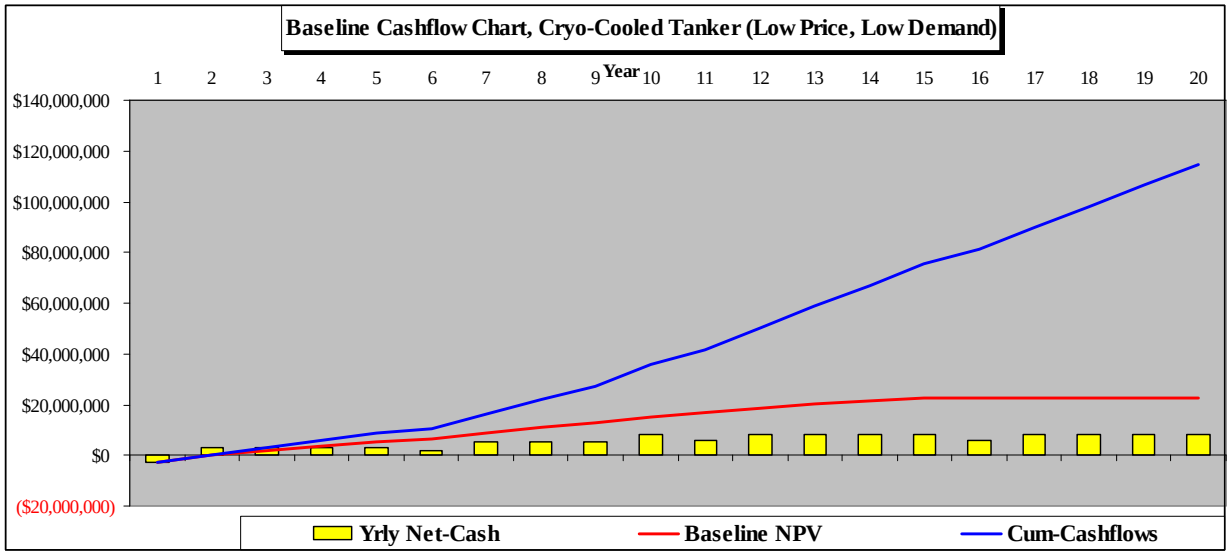

Figure 75. NPV and Cumulative Cash Flow (Cryo-Cooled Tanker, Low Price, Low Demand)

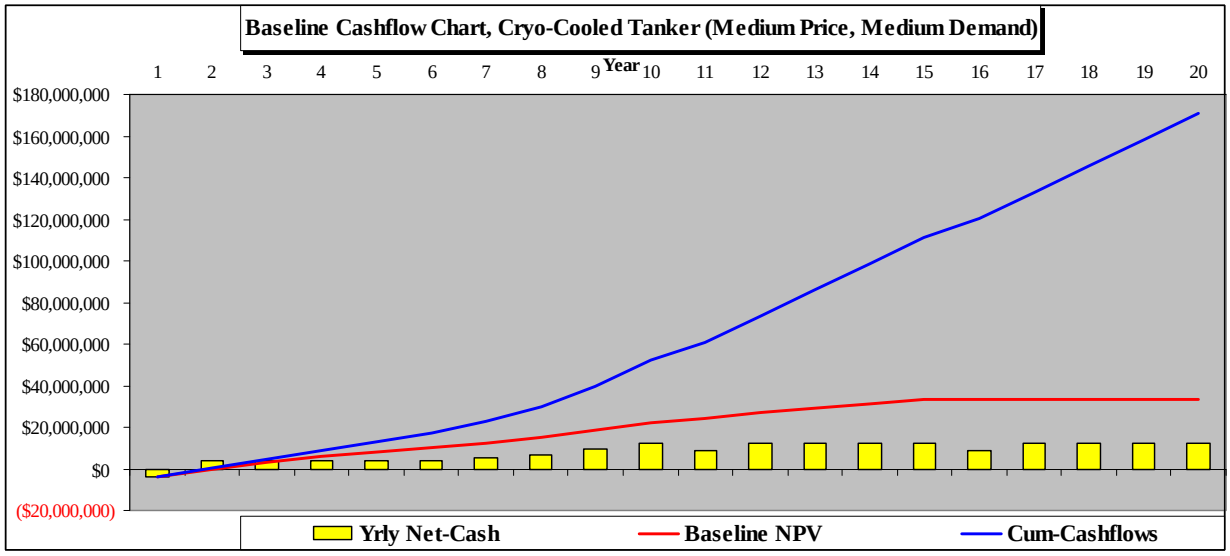

Figure 76. NPV and Cumulative Cash Flow (Cryo-Cooled Tanker, Medium Price, Medium Demand)

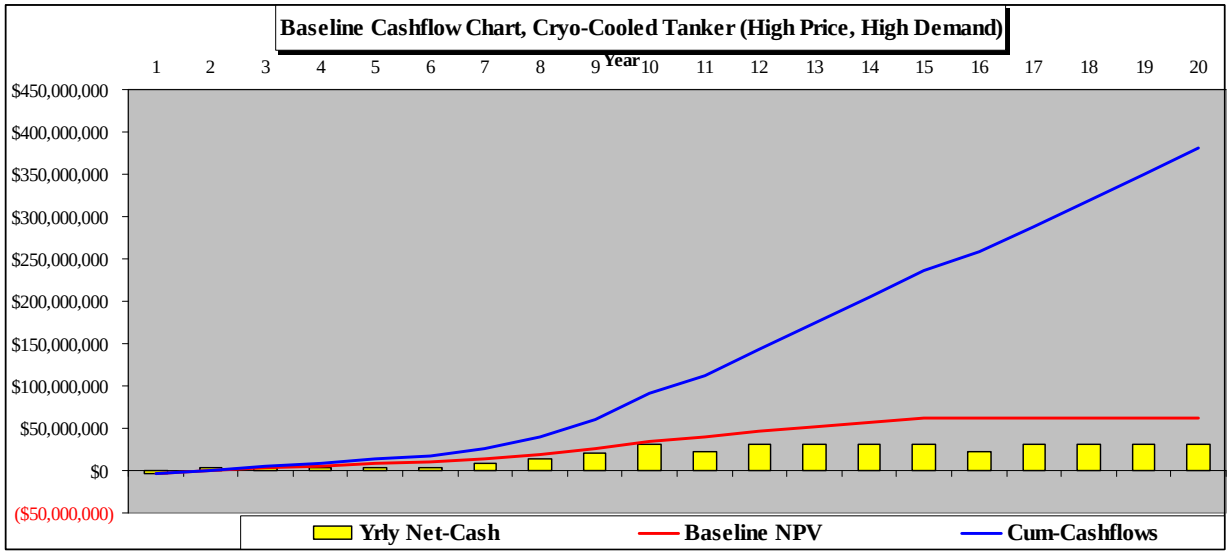

Figure 77. NPV and Cumulative Cash Flow (Cryo-Cooled Tanker, High Price, High Demand)

Appendix D: Project Best Practices

Eventually, the Project Development Process that settled on as a project can be found in Figure 1.

Team Best Practices

Appendix D.1: Stakeholder Need Analysis (Value Mapping Methodology)

- Identified stakeholder needs (utilizing the Delphi Method - VanGundy Brainwriting Level III)
- Analyzed stakeholder needs to determine underlying issues via group value mapping session:
    - Determined impact (mostly business, economic - cost, risk, time, revenue) of those issues
    - Proposed actions to remediate the issue (which was used later in forward definition of specification in QFD)
- Ranked the "Need" relative to stakeholder with relative weighting based on rank ordering
- Needs score was calculated from relative weights and rank order

Appendix D.2: Development of Quality Function Deployment (QFD)

- QFD Methodology
    - Forward definition of specifications based on values from stakeholder wants and needs
        - Solution capabilities were defined which fit stakeholder needs and addressed the underlying issue(s) defined during value mapping process
    - Evaluated specifications based on relevance and relationship to stakeholder wants and needs
    - Identified correlations between stakeholder wants and needs
- Identified relationships between the Needs and the Specifications
    - Need: low capital equipment cost, Specification: create a modular system and use parts of existing infrastructure
    - Need: hydrogen as a low cost fuel alternative, Specification: system relies on domestic production
- Identified correlations between Specifications
    - Negative correlations revealed specifications that may conflict, for example: Low cost and complies with regulations
    - Positive correlations were identified which were related and may overlap

Appendix D.3: Solution Space Reduction Methods

The following process was used to determine the systems architecture:

- The Hydrogen project established Solution Space by developing Morphological Box of alternatives which was based on the function-form mapping of architecture alternatives developed earlier

- Used head-to-head comparative matchups to reduce the number of solutions based on superiority of choices to eliminate characteristics / attributes in Morphological Box. This step may reduce the total number of combinations in the solution space or potentially reduce a dimension to the box. Also, look for categories where there is potential overlap because this may either indicate conflict within the solution space or a case where categories may be merged.
- Used Decision Tree Analysis to reduce the number of solutions based on choices starting with the vehicle application
  - Follow the decision tree process in Figure 7. The way this works is a tree is constructed using a series of decisions (based on category) which follow a logical order with respect to the system. In the case of this project the following decisions where used to construct the initial tree.

    Decision Examples: (for decision tree)

    - Decision 1 - Vehicle Application
    - Decision 2 - Distribution State
    - Decision 3 - Delivery Method
  - Since the entire delivery system needed to support the eventual vehicle application and be efficient, that dictated that the Distribution State and Delivery States be compatible with the Vehicle Application. As vehicle applications, distribution and delivery states where ruled out, this would eliminate all sub-nodes on the tree, reducing the solution space.
  - As decisions are made about the system, the decision tree is updated further reducing the solution space. In some cases, it may take several iterations for this to happen. In our project's case it took three iterations until a single solution was found (as a result of the Architecture Alternatives Analysis).

- Established a set of technology goals in order to further evaluate and grade solutions alternatives against
- Performed a Goals analysis by rank ordering goals using a similar process to the process that was employed for stakeholder analysis:
  - We isolated goals specific to a Hydrogen Delivery System which link back to Stakeholder Needs and System Characteristics identified earlier:
    - The DOE has developed and refined goals and target from many of the high-level stakeholder needs which we have identified.
    - Additional goals were derived from other needs not identified by the DOE
  - Though needs were scored by our project during earlier analysis, we needed to go through a second scoring exercise in order to rank order the goals for later architecture alternative analysis.
  - The final score will be validated against earlier results from the Stakeholder Needs Analysis

- Evaluated technologies against key goals and targets and projected whether or not the technologies would satisfy key goals by the time they would need to be employed. This information will feed the commercialization decision that will be made about the products.
- As a result of research and analysis on key distribution state technologies we made decisions which affected the solution space
- Based on the goals analysis and technology evaluation, which formed the basis of the Technology Strategy, the final alternatives were evaluated and one systems architecture was chosen,
    - In selecting a system, we isolated two key components which will impact the architecture as a whole through their choice (Vehicle Application of Storage and H2 Transport Storage)
    - We leveraged both the Stakeholder Needs Analysis and Goal Analysis methods to come up with the method of rank ordering the two alternatives,
        - Goals scores were brought forward in order to properly weight the importance of the goal against the relative ranking score (Goal Score * Relative Ranking)
        - These scores were added to obtain a Raw Score which was normalized to a value between "0" (Worst) and "1" (Best). In areas where the goal did not directly apply, a "0" was score for all of the alternatives in that category.

Appendix D.4: Configuration / Data Management (Yahoogroups)

1. All Developmental and Released data files for the project are stored at Team Hydrogen's Yahoo Group.
2. When someone checks out a file, the file name is appended with initials of person modifying the document and reposted removing the person's initials from the file, incrementing the version number and updating with today's date. Individuals on the team are notified when a file has been checked out and when it has been checked in.
3. After a file has complete development and is ready for review, it follows the review process prior to release and submission.

Appendix D.5: Review Process (Elluminate, Yahoogroups)

1. File to be reviewed has been posted to Yahoo Groups. A calendar e-mail from Outlook is sent out to the team to review the document with a meeting time to provide review comments. In the e-mail, a link to elluminate is provided in order for the document creator to present their document for review.
2. Team reviews the document prior to the review as a homework assignment and documents comments, recommended updates ahead of time as preparation for the meeting.
3. Document is reviewed and modified on elluminate in real-time to the team's satisfaction. If the team cannot agree on updates or all updates cannot be made, these further changes are made offline. If the changes are significant, a subsequent review is done. If not, changes are proposed and made via e-mail and the document is released for submission. The released document has the version number and date removed and the letters "FINAL" are appended to the name of the file (not the extension).

Appendix D.6: Requirements Traceability

- All requirements were managed in Core.
- The general approach is that a released database has 100% traceability.
- As requirements are being further refined, it is up to the systems engineer to make sure that each decomposed requirement traces back to the parent and that traceability is maintained during this process.
- Periodically, reports may be generated within Core to indicate inconsistencies in the database and to identify orphaned requirements, which may happen if any requirements are consolidated or deleted from the database.